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RELATIVE EFFECT OF ELEMENTS ON ALLOY STEELS

By John Mitchell
Metallurgical Engineer
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When an address on "Selection and Conservation of Alloying Elements Used in Steel" was first prepared for various speaking engagements before ⊕ Chapters in the winter of 1941-1942, one of the major problems confronting the makers and users of steel was the conservation of strategic alloying elements. Before the turn of the year it became apparent that there would be a shortage of certain elements even to fill the requirements of our own armed forces and to supply "lend-lease" tonnages. More intense study was then given to the allied problems of making a little alloy work to the best advantage, and of recovering and putting back into use the alloying elements in the circulating load of scrap steel. The latter work resulted in the development of the NE steels listed on page 60 by a committee of which the author was chairman, and the subject matter of the address became of double importance. The information was, in fact, used very effectively in arriving at the NE steel compositions, since it includes considerations of many items other than hardenability (which by itself quite apparently cannot provide all the answers).

This material was originally prepared for use by Carnegie-Illinois' metallurgical contact representatives as a practical guide to the relative influence of certain alloying elements in steel. When working with customers these men then had, in readily available form, information upon which to base their recommendations for using a certain element or combinations of elements in the lowest possible proportions, and yet give a steel suitable for the particular requirements. Essentially the system requires a great amount of basic information on the specific effect of individual alloying elements in steel, the analysis of such data, and their presentation in tabular and graphical form in a shape readily usable by manufacturers and users. Even though, in this presentation, the results are stated in qualitative terms rather than in definite numerical values, the utility of the presentation has been amply proven. In this rather shortened version for Metal Progress only a few of the curves can be shown; all of them are reprinted in American Iron & Steel Institute's pamphlet entitled "Contributions to the Metallurgy of Steel, No. 6; Selection and Conservation of Alloying Elements Used in Steels".

(I wish here to express appreciation to Kenneth B. Dickson and to Mary Poorman for their assistance in the preparation of material for this presentation.)

Remarks will be confined to the following elements in the ranges cited: Carbon, 0.10% to eutectoid; manganese 0.25 to 2.00%; phosphorus up to 0.15%; sulphur up to 0.30%; silicon up to 2.00%; chromium up to 1.10%; nickel up to 5.00%; molybdenum up to 0.75%; vanadium up to 0.25%; copper up to 1.10%. This will include the common engineering steels referred to as A.I.S.I. or S.A.E. analyses. By including copper and extending the limits of phosphorus and molybdenum over those normally used, it is possible to include in the proposed plan a wide variety of the common flat-rolled steels.

When the elements exceed the maximum

limits noted above, our plan of appraisal is not generally applicable, as the presence of some elements in greater quantities tends to impart a reverse or quite different effect. It must also be assumed that the steel will be given the proper heat treatment and processing.

Further, the proposed scheme relates only to the fine-grained steels, except in the instances of flat-rolled steels (such as sheet or plate) and those steels known as free-cutting (such as bessemer screw stock, or resulphurized openhearth free-cutting steels). With the exception of the special, stainless, or toolsteel grades, the merit rating plan to be suggested covers the major portion of steel production and consumption.

Basis of Appraisal

At the outset the influence of varying amounts of a certain element (like chromium) on a certain property of steel (like hardenability) was analyzed. In this case it is common knowledge that chromium is a very potent element for increasing hardenability, and that when the chromium is increased from say 0.25 to 0.50%, the 0.25% chromium is more effective than though it were added to a 0.75% chromium steel to make one containing 1.00% chromium. These facts are expressed in the upper left curve of Fig. 1.

To indicate in a tabular, qualitative manner whether the elements have a favorable or unfavorable effect, a weak or a strong action, upon the properties of steel or its response to certain processing operations, we have adopted an arbitrary system of merit ratings. Rating numbers vary from zero to +10 where the element is favorable and from zero to −10 where use of the element is detrimental to the results desired. In the representative case of chromium, the effect on depth of hardening has been fixed at +7, in accordance with the following schedule or key:

+10 = Strong favorable effect
+ 7 = Moderate to strong favorable effect
+ 5 = Moderate favorable effect
+ 2 = Mild favorable effect
+ 1 = Slight favorable effect
0 = Little or practically no effect
− 1 = Slight unfavorable effect
− 2 = Mild unfavorable effect
− 5 = Moderate unfavorable effect
− 7 = Moderate to strong unfavorable effect
−10 = Strong unfavorable effect

Suffix letters are used in connection with all rating numbers to indicate the characteristic influence of the added element. Thus, when the influence of the element appears to be approximately proportional in intensity to the amounts present, a linear function is assumed to exist. This "straight line" or proportional influence is indicated by the suffix letter "P". Where elements function with relatively greater intensity at low concentrations, the merit rating number is followed by the letter "S" to indicate that *small* quantities are most effective. Conversely, when moderate additions appear to exert only a relatively minor effect while greater additions exert a disproportionately strong influence, the merit rating number is followed by the letter "L" to indicate that *large* amounts are necessary. In the few instances where some certain effect reaches a maximum at an intermediate point on the curve and then decreases in intensity as more of the element is added, the merit rating number is followed by the letter "I" to indicate that *intermediate* amounts of the element are most effective in securing the desired effect.

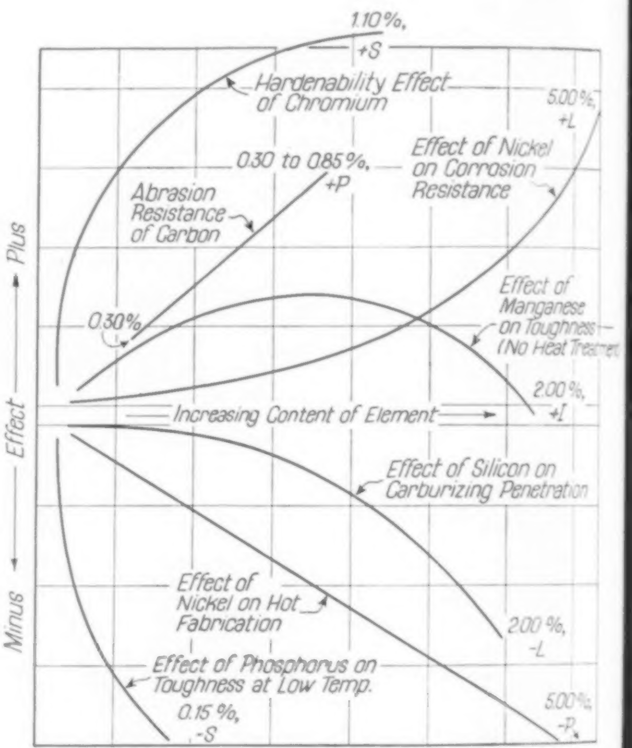
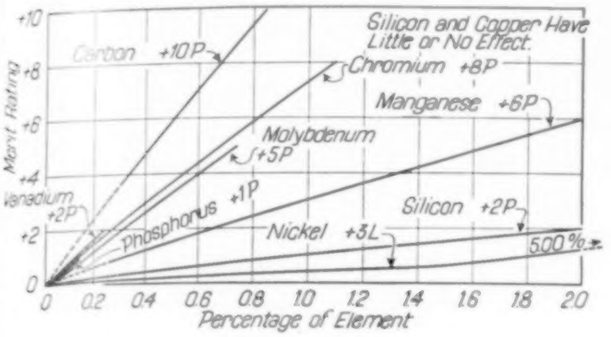


Fig. 1 — Curves Showing in a Qualitative Way the Effect of Certain Common Alloying Elements on Representative Properties of Steel. Figures represent maximum limits of alloys considered; letters indicate whether influence of the element is strongest in small quantities (S), in relatively large quantities (L), in intermediate quantities (I), or is proportional to its amount present (P)

Fig. 2 — Approximate Characteristic Curves of Relation of Alloy Content to Wear Resistance After Full Quench and Draw to 300 to 400° F.



In assigning merit ratings, the shapes of the curves designated by the suffix letters were considered as being just as important as the number itself. Thus, while it is not possible to determine the exact limits of the elements needed to achieve a desired end, the suffix letter indicates whether large or small amounts of any element are most effective, the number itself indicating the degree of favorable or unfavorable effect. Neither numerals nor letters alone can be used as a guide.

The example of chromium has already been cited. Figure 1 shows that the function of carbon as regards abrasion is a straight line in medium and hard steels, so we have the plus "P" curve noted in the table, page 56. (In mild steels the carbon must be on the high side to have any appreciable effect, so the rating is +3L.) Large amounts of nickel are required to develop maximum corrosion resistance, while small quantities are relatively ineffective, which establishes the plus "L" curve. Where hot fabrication is involved as in rolling or forging, the nickel function is a straight line, shown as the minus "P" curve. Small percentages of silicon are not relatively as harmful to the carburizing operation as are large amounts, as indicated by the minus "L" curve. Small percentages of phosphorus exert a strong influence on the toughness of steel at low temperatures, so the minus "S" curve is assigned. In the case of manganese, maximum effects are secured on the property of ductility in the hot-rolled condition by the use of intermediate amounts, this effect being shown by the plus "I" curve in Fig. 1 and the rating of +2I in the table.

When using the table on page 56 as a basis for making comparisons, it must be remembered that the merit ratings have been developed by considering the effect of the various elements upon plain carbon steel such as 1015, 1020, or 1030 with a minimum of 0.10% carbon and 0.25% manganese (except in the case of flat-rolled steels). Further, the user should bear in mind that the composition is being built up by the use of a single alloying element as listed, such as 3½% nickel, or 1.00% chromium, or 2.00% manganese. In this way the user can study the effect of a single alloying element on a low or medium carbon base composition.

Unless specifically noted, merit ratings are based upon use of the maximum percentage shown for each element. Two columns have been assigned to carbon, covering the ranges 0.10 to 0.30% and 0.30 to 0.85%. The ratings relating to welding, corrosion, and deep drawing properties are based on a carbon range of zero to 0.30% instead of 0.10 to 0.30%. When making comparisons between effects of elements other than carbon and manganese in two specific steels, see to it that the carbon and manganese content is the same. The proper amounts of these two elements, carbon and manganese, are essential in any steel.

There may be some difference of opinion as to precise merit rating numbers — whether, for example, a number should be +5 or +7. Such small differences, however, will have little influence on the final result, as will be seen later. The table has been developed in broad terms and is primarily intended to outline *trends* that metallurgists would accept as reasonable. No attempt has been made to reduce the science of metallurgy to mathematics.* Rather, the tables should be considered as a source of information which will be useful as a reasonable guide in the selection, conservation and economical utilization of alloying elements. They also enable one to determine roughly the relative amount of each element required to influence a property or reaction to the degree desired.

Specific Examples

In the following paragraphs will be outlined briefly some of the principal points which were weighed in assigning merit ratings.

Wear Resistance ratings (Fig. 2) were assigned on the assumption that the steel will harden thoroughly with no free ferrite present, preferably to about 600 Brinell or Rockwell C-60, and when compared will have equal carbon contents.

Annealing for Pearlite. Merit ratings take into consideration the effect of the various elements

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*A notable exception is GROSSMANN's computation of hardenability from the chemical composition, summarized on page 80 and the data sheet, page 81.

Relative Merit of Alloys in Steel as Regards Influence on Specific Properties or Responses

	Carbon 0.10 to 0.30%	Carbon 0.30 to 0.85%	Manganese 0.25 to 2.00%	Phosphorus Up to 0.15%	Sulphur Up to 0.30%	Silicon Up to 2.00%	Chromium Up to 1.10%	Nickel Up to 5.00%	Molybdenum Up to 0.75%	Vanadium Up to 0.25%	Copper Up to 1.10%
Abrasion Resistance; Steel as rolled, as forged, or normalized	+3L	+10P	+8L	0	0	+2P	+7P	+3P	+4P	0	+1P
Wear Resistance; Steel fully hardened (no free ferrite) to C-60, drawn at 300 to 400° F.	0	+10P	+6P	+1P	0	+2P	+8P	+3L	+5P	+2P	+(?)
Annealing; Degree of accuracy necessary to control temperature when annealing to lamellar pearlite	+3L	+5P	−2L	0	0	−2P	+3P	−5P	−3L	+2P	−(?)
Carburizing; Depth of case only	0	−4P	+5P	0	0	−10L	+2P	−3P	−2P	+2P	−10L
Corrosion in atmosphere or weakly corrosive liquids	−3P*	−6P	0	+10P	−10P	+2P	0	+6L	+2P	0	+10S
Creep Resistance at temperatures up to 950° F.; Steels drawn at higher temperatures	+2I	−3P	0	0	0	0	+1P	0	+10P	?	?
Distortion on Oil Quenching, and susceptibility to quench cracks (Effect of volume change at transformation)	−1P	−2P	−4P	−3P	0	−1P	−4P	−2P	−3P	−1I	0
Distortion on Water Quenching and drawing (and susceptibility to quench cracks)	−2P	−4P	−7P	−6P	0	−3P	−7P	−7L	−5P	−2I	−(?)
Fabrication in Deep Drawing; Breakage of strip or sheet	−4P*	−10P	−10P	−10P	−10P	−10S	−10S	−10S	−10P	−(?)	−10P
Fabrication in Cold Bending	−2L	−10P	+2I	−10L	−7P	−6P	−10P	+5S	+3S	+3P	+2P
Hot Workability; Formation of seams, scale, decarburized skin, resistance to flow	+2P	−7P	+7S	0	−10S	−5P	0	−6P	−3P	0	−10S
Hardenability or hardness penetration (Basis: Steel with 0.70 to 1.00% manganese)	+1P	+2P	+10P	+3P	−2P	+2S	+7S	+10L	+7S	+5I	+(?)
Machinability; Steel as rolled, as forged, or normalized	+2P	−2P	−6P	+6P	+10P	−2P	−2P	−10P	−5P	0	−(?)
Machinability; Steel annealed to maximum lamellar pearlite	+2P	+3I	−2L	+6P	+10P	−2L	−2P	−10P	−4P	−1P	−(?)
Machinability; Steel quenched and drawn to 300 Brinell	0	0	−2L	+4P	+8P	−2P	0	−10P	−4P	0	−(?)
Machinability; Steel quenched and drawn to 400 Brinell	0	0	−4L	+2P	+3P	−2P	0	−10P	−4P	?	−(?)
Strength; Steel as rolled, as forged, or normalized	+4P	+10P	+5P	+5P	−2P	+7P	+5P	+5P	+5P	0	+1P
Toughness at Room Temperature (as judged by reduction of area in the tensile test or by notched bar impact test); Steel as rolled, or as forged	−3P	−8P	+2I	−8P	−6P	−2P	−8P	+10P	+3S	+2P	+1L
Toughness; Steel as normalized	−2P	−6P	+3I	−6P	−4P	−2L	−6P	+10S	+5P	+5P	+2P
Toughness; Steel fully quenched and drawn to 300 Brinell	0	−1P	0	−5P	−3P	0	0	+6P	+2S	+1P	+(?)
Toughness; Steel fully quenched and drawn to 400 Brinell	0	−2P	0	−6P	−3P	0	0	+7P	+4S	+2S	+(?)
Toughness; Steel fully quenched and drawn to 300 to 400° F.	0	−8P	−4L	−10P	−5P	+2L	−8P	+10S	+4S	+3S	+(?)
Toughness at Room Temperature; Steel fully quenched and drawn to 400 to 600° F.	0	−2P	−4P	−4P	0	0	−5P	−2I	0	0	?
Toughness at −50° F.; Steel as rolled or as forged (Basis: Notched bar impact test, specimen at −50° F.)	−3P	−10P	+2I	−10S	−6P	−1P	−10P	+10S	+3S	+3P	+(?)
Toughness at −50° F.; Steel as normalized at 1650° F., but below grain coarsening temperature	−3P	−10P	+2I	−8P	−4P	−1L	−8P	+10S	+5S	+5P	+(?)
Toughness at −50° F.; Steel fully quenched and drawn to 300 Brinell	0	−2P	0	−5P	−3P	0	0	+10P	+2S	+1P	+(?)
Toughness at −50° F.; Steel fully quenched and drawn to 400 Brinell	0	−5P	0	−7P	−4P	+2P	0	+10S	+4S	+2S	+(?)
Toughness at −50° F.; Steel fully quenched and drawn at 300 to 400° F.	0	−10P	−8L	−10P	−6P	+2L	−10P	+10S	+4S	+4S	+(?)
Weldability; Susceptibility to small ruptures when fusion welding without preheating or post heating	−2L*	−10P	−10L	−7L	−3P	−5L	−10L	−10L	−10L	+1P	−4L

*Rating based on carbon range of 0.0 to 0.30%.

Code: Zero to +10 for strongest favorable effect.
Zero to −10 for strongest unfavorable effect.
P means effect is proportional to amount of alloy.
S means small quantities are most effective.
L means large quantities, near the top of the range, are needed.
I, that intermediate amounts are most effective.
+(?) means probable positive influence.
−(?) means probable negative influence.

upon the degree of accuracy necessary in controlling heating and cooling cycles to produce lamellar pearlite. Normally, those elements which lower the transformation temperature in cooling, carbon excepted, require closer control. Note that the strictly carbide-forming elements (carbon, chromium, and vanadium) are helpful. Manganese and molybdenum have a weak negative effect and nickel has a moderate negative effect. See Fig. 3 and the table opposite.

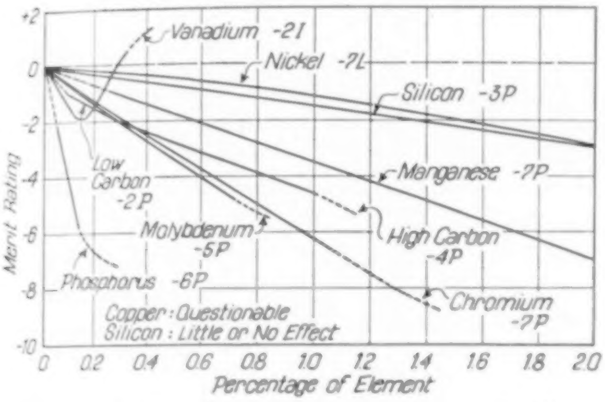

Fig. 3 — Curves Showing the Relation of Alloy Content to Distortion of Water Quenched Parts

Carburizing ratings have been assigned with reference to the depth of case and have no relation to its carbon concentration. Silicon and copper are the most harmful, particularly if exceeding 0.75% Si or about 0.60% Cu. Certain amounts of silicon, however, might well be considered as a means of controlling carbon *concentration;* with about 1.00% there is no excess carbide. This is ideal for some applications, although longer time cycles or higher temperatures may be necessary to produce the desired depth.

Corrosion. It has been assumed that the steel will be pre-treated in accordance with accepted and proved practices which render it most resistant to attack — for example, stress relieved if unduly cold worked. Steels are not ordinarily quenched and drawn to increase corrosion resistance. In the case of sucker rods, however, heat treatment is commonly used to improve physical properties. Copper and phosphorus are the most effective elements, although nickel in large amounts is beneficial. Sulphur and carbon have some detrimental effects.

Creep Resistance is affected by the heat treatment applied prior to use and the temperature to which the steel will be subjected. Flat-rolled steels are generally annealed or normalized; or normalized and drawn in excess of 1000° F. Treatment of high temperature bolts generally consists of quenching followed by drawing in excess of 950° F. If bars are cold worked subsequently, they are stress relieved to elevate the elastic limit.

Carbon up to 0.20% and chromium are slightly helpful for creep resistance; molybdenum is by far the most effective alloy of the group.

Distortion, or volume change on quenching in water, is shown in Fig. 3. Similar curves, although about one-third as steep, would be drawn for the effect of oil quenching.

Approximately the same ratings apply as to susceptibility to quench cracking, when made upon the assumption that the basic composition is low in hardenability and that, as the hardenability is increased by the addition of an element, danger of cracking increases (except in the case of large amounts of vanadium). These ratings on quench cracking do not apply to any method of time quenching where sections are removed from the quench above bath temperatures.

Distortion is dependent upon several factors, one being the effect of the element upon hardenability with its attendant volume changes. In severely contrasting sections which have distorted badly during quenching, the distortion may be aggravated when the piece is tempered and the residual stresses relieved.

To compare relative distortion critically, all the factors involved must be identical; carbon content, section, hardenability, quenching speeds, and so on. Generally speaking, and for ordinary applications, the results will be roughly the opposite of those noted for depth of hardenability. Such a simple rule does not apply in all cases. For example, where insufficient hardenability, caused by use of too little of an element, results in non-uniform quenching and distortion, the difficulty can be minimized by more alloy.

Fabrication properties, generally speaking, are opposite to hardenability — that is, any element which increases hardness is detrimental to deep drawing qualities. This applies to any state in which the product might be furnished — as-rolled, normalized, or annealed. The various alloying elements reflect different phases which must be considered both separately and combined when assigning ratings to deep drawing ability; for example, whether the element added reduces the ductility; what effect the element has upon the response to annealing to produce the lowest possible hardness; whether the added element is a carbide former or ferrite toughener; whether the element tends to increase or decrease the ratio between the elastic limit and ultimate strength; whether the element added is one which causes a high degree of cold working effects during deformation, thereby causing premature ruptures.

The effects of the elements upon simple cold forming and bending are somewhat different from their influence upon deep drawing; those which impart ductility as measured by the tensile or impact test resist breakage in forming operations.

Fatigue resistance, which is very important, has been omitted purposely, as so much depends upon the effect of the mechanical design, the surface character and the environment. It is therefore difficult to assign merit ratings as might be derived from laboratory tests.

Hardenability, or depth of hardening, merit ratings should not be confused with the maximum intensity of hardness obtainable, which is mainly a function of the amount of carbon present. The vanadium curve assumes a sharp maximum principally because it would be impractical to raise the quenching temperature high enough to take all the carbide into solution; hence, with the remaining undissolved carbide "tied up", a lowering of relative hardenability occurs in the higher ranges of vanadium.

Since depth of hardening is dependent upon quenching speed as well as the composition of a steel, both factors must be taken into consideration when choosing the proper steel for a specific size. To do this most effectively other data should be consulted, as, for example, cross-sectional and end-quench hardenability curves of steels of equivalent analyses, as found in various publications, or the computations as outlined by Marcus A. Grossmann on page 80 may be made.

Hot Workability. This over-all appraisal includes consideration of several factors. Certain elements have an effect upon surface conditions such as seams, scabs, ruptures, excessive decarburization, adherence of scale; others upon resistance to flow, which causes surface imperfections such as crowding of metal; other elements increase susceptibility to burning or to red shortness. Carbon aggravates burning; sulphur and copper contribute to red shortness, seams or injurious surface breaks; silicon causes resistance to flow and certain surface imperfections; nickel causes scale adherence and resistance to flow; molybdenum increases resistance to flow. Sulphur, silicon, nickel, and copper do not favor hot work, while manganese is beneficial. See Fig. 4.

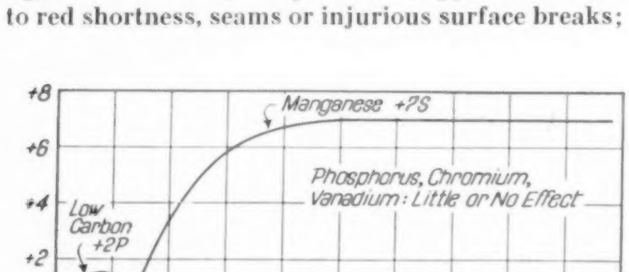

Fig. 4 — Curves Showing the Approximate Influence of Alloys on Hot Rolling or Forging Properties, Such as Resistance to Flow, and the Formation of Seams, Scale, Decarburized Skin

Machinability ratings have been assigned with relation to the hardness, strength, ductility, or a combination of all three and their effect on machinability.

A decrease in machining properties may ordinarily be expected from *(a)* those elements which increase the hardness or strength and effect an increase in ductility, *(b)* those elements which increase the strength and hardness only, and even *(c)* those elements which have high air hardening properties increasing the strength and hardness rapidly although slightly decreasing the ductility. Phosphorus and sulphur improve the machining properties, regardless of the other elements present.

As a rule, low carbon steels are machined in the "as-rolled" or "as-forged" condition. The higher carbon steels are generally annealed, or in some cases normalized.

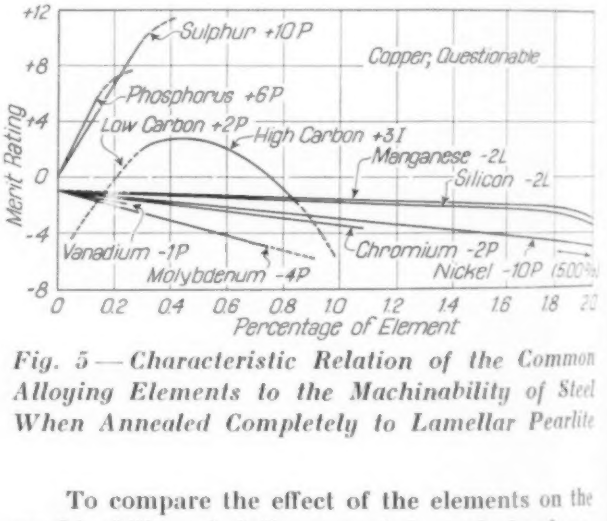

Fig. 5 — Characteristic Relation of the Common Alloying Elements to the Machinability of Steel When Annealed Completely to Lamellar Pearlite

To compare the effect of the elements on the machinability of fully annealed steel, hardness, strength and ductility should be as nearly identical as possible. Unavoidable variations in hardness and toughness have been taken into consideration in assigning merit ratings. Strictly carbide-forming elements would be preferred for improving machinability; those which combine with carbon and also exist in solution in the ferrite would come second, and those which exist entirely in solution in the ferrite are least desirable. See Fig. 5.

When steel is heat treated to 300 or 400 Brinell, it appears that the elements affect machinability somewhat in inverse relation to their effect on toughness as measured by a notched bar impact test, or by reduction of area in the tensile test, and not necessarily in relation to the ductility as measured by elongation. To compare the effect

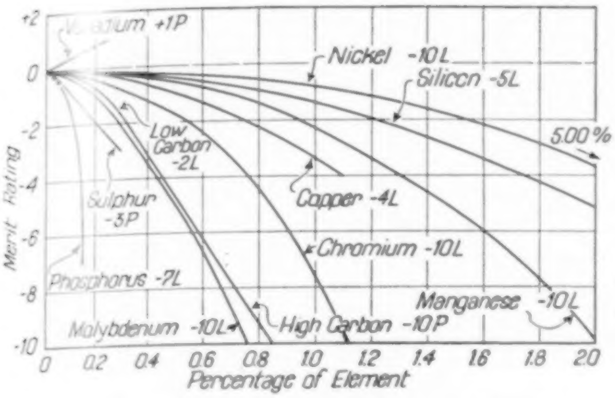

Fig. 6—Curves Showing the Effect of Alloys on the Formation of Ruptures in Fusion Welded Joints, Not Preheated or Post Heated. Low carbon effect is based on the carbon range 0 to 0.30%

of the element in hardened steels, the composition of the steel must be such as to harden thoroughly, preferably to about 550 Brinell or commensurate with the maximum hardness obtainable for the type, without any free ferrite grain boundaries (detrimental to machining, particularly drilling or forming). Note that the improvement imparted by phosphorus or sulphur decreases as the hardness increases.

Strength appraisals are based on a section of as-rolled, as-forged or normalized steel small enough to reflect to a considerable degree the air hardening properties of the composition being studied. As the sections increase, the relationships shown in the table are less applicable.

Toughness at Room Temperature is judged in relation to the figures for reduction of area in the standard 0.505-in. tensile test bar, or the ft-lb. of energy absorbed upon fracturing a 10-mm. square bar (0.394 in.) with standard V notch. To make accurate comparisons, the hardness of the steels should be identical. Because of the individual characteristics of each element this is practically impossible to attain. This difference in characteristics has been taken into consideration in assigning merit ratings. All comparisons have been made upon the basis that the same cross-section exists.

Toughness ratings on heat treated steels, tested at room temperature, hold true whether the sections are oil or water quenched, the principal requirements being that the steel will harden thoroughly to about 550 Brinell, free from any ferrite grain boundaries, and that the carbon content be about the same in the comparison steels. The toughness here involves differences to be found by notched bar impact tests; when steels are thoroughly hardened and subsequently drawn in ranges up to approximately 400 Brinell, the effect of the elements upon ductility is small. For hardnesses above 400 Brinell up to the maximum obtainable for the type, the effect of the elements becomes more pronounced.

The effect of some of the elements is modified by the brittleness developed by drawing between 400° and 600° F., as shown by notched impact tests on fully hardened specimens drawn in increments of 25° F. starting at about 300° F. and continuing to 650° F. It will be found that there is some loss in ductility in most types of steel although the percentage of loss will vary from one type to another. Merit ratings reflect this relative percentage of loss.

Toughness at Low Temperature is rated on the effect of the elements at temperatures down to about −50° F., as measured on a notched bar impact test. Comparisons are based on equivalent hardness values, as nearly as possible. Due consideration has also been given to their air-hardening and toughening characteristics.

Normalized steels should be heated in the neighborhood of 1650° F., but below the grain coarsening temperature of the particular steel.

Weldability (Fusion). Merit ratings have been assigned with due regard to the relative hazard which exists when no preheating or post-heating is used as a precaution against ruptures in or adjacent to the welds. A direct relation exists between the air hardening properties of the elements and their effects upon rupture. See Fig. 6.

A Sample Appraisal

While these merit ratings in the table on page 56 may be used in several ways, let us consider their use in estimating the chances for improving a mild plain carbon steel in a use which demands abrasion resistance, strength and toughness in the as-rolled condition, the ability to fabricate by cold bending, and weldability. The adjoining table shows the sum of all the favorable and unfavorable merit rating

Appraisal of Steel for Welded Excavating Machinery

PROPERTY	C *(a)*	MN	P	S	SI	CR	NI	MO	V	CU
Abrasion resistance	+3L	+8L	0	0	+2P	+7P	+3P	+4P	0	+1P
Strength *(b)*	+4P	+5P	+5P	−2P	+7P	+5P	+5P	+5P	0	+1P
Toughness *(b)*	−3P	+2I	−8P	−6P	−2P	−8P	+10P	+3S	+2P	+1L
Bending	−2L	+2I	−10L	−7P	−6P	−10P	+5S	+3S	+3P	+2P
Weldability	−2L *(c)*	−10L	−7L	−3P	−5L	−10L	−10L	−10L	+1P	−4L
Plus totals	+7	+17	+5	+0	+9	+12	+23	+15	+6	+5
Minus totals	−7	−10	−25	−18	−13	−28	−10	−10	−0	−4

(a) Effect of carbon in the 0.10 to 0.30% range.
(b) For steel as-rolled.
(c) Effect of carbon in the 0.00 to 0.30% range.

values for each element upon all the properties or responses involved in this hypothetical set of conditions. The individual lines were taken from the large table, page 56.

It will be noted all the favorable and unfavorable points have been summed up separately in this small table. These totals merely call attention to the fact that sometimes there are as many unfavorable points as favorable points for a certain element. The problem therefore confronts the user of such a table of making a decision as to where and to what extent compromises must be made in an attempt to select the most suitable composition. It is not recommended that the numerical totals alone be considered as the guide, since the suffix letters in each individual case must also be weighed to arrive at a conclusion in the proper selection of the necessary alloying combinations.

It must also be recognized that the totals are applicable when the maximum amount of element shown in the heading of the large table (page 56) is present, and will change in accordance with the suffix letters.

The small table also is an example of how an appraisal may be made for practically any application. While such tables will not necessarily give the exact combination for best performance under all shop conditions, they will guide the user in choosing the most promising elements and they will indicate whether small or large quantities are required for a property or a response. They will also indicate clearly what sacrifices must be made in one direction to secure desirable properties sought in another direction. Thought must be given to the relative effect of each 0.01% of an element necessary to impart the properties desired. If weighed carefully by relative 0.01% increments, the information presented in this paper will guide the maker and user of steel in the economical use and conservation of strategic elements.

We have found these tables to be particularly helpful in discussing problems with mechanical engineers who have not been able to keep abreast of all the metallurgical advances involved in steel selection or performance. They also reveal why it is sometimes necessary to have combinations of alloying elements.

Use in Formulating NE Steels

At present the trend is to standardize on fewer types of steels and the use of smaller amounts of alloys, depending upon improvements in steel manufacturing processes, improved heat treating technique, or better design of the parts, to permit the use of the least amount of the alloy.

In line with this idea, national emergency steels known as the NE8000 series, involving compositions of manganese and molybdenum and low percentages of chromium, nickel and molybdenum, were established by a committee consisting of representatives from the Technical Committee on Alloy Steel of American Iron and Steel Institute, cooperating with representatives of the Society of Automotive Engineers and interested ferro-alloy manufacturers. All but two of the 29 committee men are ASMembers.

Compositions were selected on the basis of the end-quench method of determining hardenability. This method was chosen as being the most rapid and practical means of comparing all types of constructional alloy steels. When sections or parts are properly treated, it affords an accurate guide to the relative possibilities of steels of different compositions. It is recognized that the hardenability test alone is not the only factor that must be considered when selecting a steel, consequently the other factors must be studied in connection with the data previously presented, plus the corresponding curve sheets published in full in the document mentioned at the outset (page 53).

National Emergency Alternate Steels

DESIGNATION	CHEMICAL COMPOSITION				
	C	MN	MO	NI	CR
NE8024	0.22-0.28	1.00-1.30	0.10-0.20	....	....
NE8124	0.22-0.28	1.30-1.60	0.25-0.35	....	....
NE8233	0.30-0.36	1.30-1.60	0.10-0.20	....	....
NE8245	0.42-0.49	1.30-1.60	0.10-0.20	....	....
NE8339	0.35-0.42	1.30-1.60	0.20-0.30	....	....
NE8442	0.38-0.45	1.30-1.60	0.30-0.40	....	....
NE8447	0.43-0.50	1.30-1.60	0.30-0.40	....	....
NE8547	0.43-0.50	1.30-1.60	0.40-0.60	....	....
NE8620	0.18-0.23	0.70-0.95	0.15-0.25	0.40-0.60	0.40-0.60
NE8630	0.27-0.33	0.70-0.95	0.15-0.25	0.40-0.60	0.40-0.60
NE8724	0.22-0.28	0.70-0.95	0.20-0.30	0.40-0.60	0.40-0.60
NE8739	0.35-0.42	0.75-1.00	0.20-0.30	0.40-0.60	0.40-0.60
NE8744	0.40-0.47	0.75-1.00	0.20-0.30	0.40-0.60	0.40-0.60
NE8749	0.45-0.52	0.75-1.00	0.20-0.30	0.40-0.60	0.40-0.60
NE8817	0.15-0.20	0.70-0.95	0.30-0.40	0.40-0.60	0.40-0.60
NE8949	0.45-0.52	1.00-1.30	0.30-0.40	0.40-0.60	0.40-0.60

WAR PRODUCTS CONSULTATION

Bronze Gear Alloys

The Problem

Raised by a Manufacturer of Gear Drives

ON ACCOUNT of the shortage of tin, which may soon amount to a total prohibition, it is important to develop a substitute for the tin bronzes. Our particular interest is bronze worm gears in heavy duty drives; we have been using a chill cast nickel-phosphor bronze containing about 11% tin. The metal must be structurally strong, be a good bearing metal and should develop a hard skin under heavy sliding surface loads.

We did quite a lengthy research on various materials for worm gear drives in 1931-34, which culminated in the selection of the chilled nickel-phosphor bronze already mentioned. We propose to repeat this with only one variable — the gear alloy — but first we need to know the mixtures for an alternative bronze for heavy duty gears.

Tentative Solutions

From an **Automotive Manufacturer** — Duplication of physical properties could probably be accomplished by substituting silicon for the tin, but some anti-scoring properties will be sacrificed. All our test information indicates that bronzes containing zinc, manganese, silicon or aluminum are inferior to nickel-tin bronzes for frictional purposes. I would retain the nickel and substitute silicon alone — or possibly silicon and manganese — to replace the tin.

From an **Electric Furnace Operator** — We have used the high-tensile cast manganese bronze described in ⊕ Handbook, page 1432, for large nuts in the tilting devices on our electric furnaces, and find they are giving results comparable with the nickel gear bronze we formerly used.

From a **Maker of Heavy Mill Machinery** — We have replaced bronze worm gears with Meehanite cast iron worms in boring mills, and have found the service superior to the bronze formerly used. These worms were used as-cast. In another installation, heavy duty bronze worms and gears in a ball grinding machine were replaced with this special cast iron heat treated to 300 Brinell. These worms and gears in both installations replaced bronze to overcome seizing and wear.

From a **Shipbuilder** — On worm gears, irrespective of the contact speeds, we would suggest a silicon bronze,[*] specifically a 3% silicon (tin-free) "bronze" hardened with about 1½% iron. This is the well-known "P.M.G. alloy", patented by the British firm Vickers-Armstrong. It is corrosion resistant and work hardens readily. Aluminum bronzes will be satisfactory for slow moving worm gears, where the contact speeds are less than 300 ft. per min.

From a **Bronze Manufacturer** — As we see it, there is going to be a heavy swing from the tin bronzes toward the manganese bronzes, since they not only use little or no tin, but they also conserve scarce copper by using more of the available zinc. However, we have never recommended manganese bronze for bearings or worm gears. This leaves aluminum bronze as an alternative, and fortunately it can be made with secondary aluminum now procurable.

Aluminum bronze is definitely stronger than the nickel-tin gear alloy; it also forms a hard skin under sliding surface loads, and has the necessary toughness. We have supplied many worm gears in aluminum bronze in either of the following: Composition 1; Copper 89.0, aluminum 10.0, iron 1.0%, and Composition 2; Copper 86.0, aluminum 10.5, and iron 3.5%.

The latter material, because of its higher iron content, is generally considered to have greater wear resistance. Both are "duplex structure materials" in which there is more than one metallographic phase present[†] — a definite advantage over the lower aluminum alloy, which has only one phase present, and also, for the same reason, over the so-called high tensile manganese bronze alloys.

The Result

"We have made two series of 'tests to destruction' on different alloys and are now working on others. The two were silicon bronzes and each carried the rated load of a chilled nickel-tin bronze of similar size. That is just one third the load value of the latter, or, said differently, the factor of safety would be unity instead of three. At the same time we ran a test on the nickel-tin bronze to check our base line. It did check exactly.

"We are still searching for new and promising combination alloys, especially with duplex structure, and would like to hear further suggestions from ASMembers." ⊕

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[*] These have been described systematically in METAL PROGRESS for March 1938, page 258.

[†] See METAL PROGRESS, December 1940, page 789.

SOME FACTORS AFFECTING THE DRAWABILITY OF ALUMINUM SHEET

**By G. A. Brewer, V. N. Krivobok
and Mabel M. Rockwell**
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Lockheed Aircraft Corp.
Burbank, Cal.**

TWO ARTICLES have already been published in METAL PROGRESS on the wedge-draw test for determining the ability of sheet metal to draw deep cups from circular blanks. In this final brief note some remarks on the effect of grain size, and on useful extensions of the test program, will be made.

Some tests were made to investigate the effect of fine and coarse-grained microstructure on the formability of 24S-O alclad. Seventy-eight wedges of 0.051-in. sheet were drawn; 56 of them were of fine-grained material, and the remaining 22 had coarse grain. Chemical constituents of the two materials were found to be, for all practical purposes, identical.

Formability of the coarse-grained material was good and also uniform — that is, the reductions obtainable *across* the grain were the same as those obtainable *with* the grain. On the other hand the fine-grained material showed pronounced directional properties; reductions obtainable *with* the grain were less favorable than those obtainable *across* the grain. This marked difference in directional properties indicates, we believe, a preferred orientation in this material, rather than a specific effect of grain size. The accompanying table compares the fine and coarse-grained wedges. It shows that the coarse-grained material, when such material is composed of randomly oriented crystals, is superior for deep drawing to fine-grained material if the latter has a structure involving preferred orientation of the crystals. Preferred orientation evidences itself in shear failure in the wedges, and would be revealed by pronounced earing tendencies in cups (due to the directional effects which would come in before actual shear failure). The net result in either case would be that the fine-grained material could not be drawn to the same depth as the coarse-grained material.

Drawing Properties of Fine and Coarse-Grained 24S-O Alclad

NUMBER OF TESTS	GRAIN SIZE	TESTING DIRECTION	$r:R$ RATIO	
			MINIMUM *(a)*	MAXIMUM *(b)*
12	Coarse	With	0.505	0.522
10	Coarse	Across	0.517	0.525
15	Fine	With	0.540	0.557
8	Fine	Across	0.508	0.525
33	Fine	45°	0.48–	0.49

(a) Below this ratio failure always occurs.
(b) Above this ratio failure does not occur.

The effect of prior cold work on grain size *after* heat treatment is shown in Fig. 1, which shows coarse-grained material which was originally 24S-O, but was drawn in the wedge fixture described in previous articles, and then solution heat treated.

The short strip is from an unworked corner of the specimen. The lower end of the long strip represents the throat end of the wedge, which was therefore subjected to comparatively little drawing or cold work. Locations further up the strip represent locations further along the wedge, receiving progressively greater amounts of cold work. It is seen that the metal which was subjected to considerable cold work, due to the drawing strain, retained a very fine grain size after solution heat treatment, while in material which had not been cold worked it is virtually unchanged. Recrystallization during heat treatment is evidently affected by the prior history of cold work. There is a definite critical degree of cold work, as indicated by the relatively narrow transition zone.

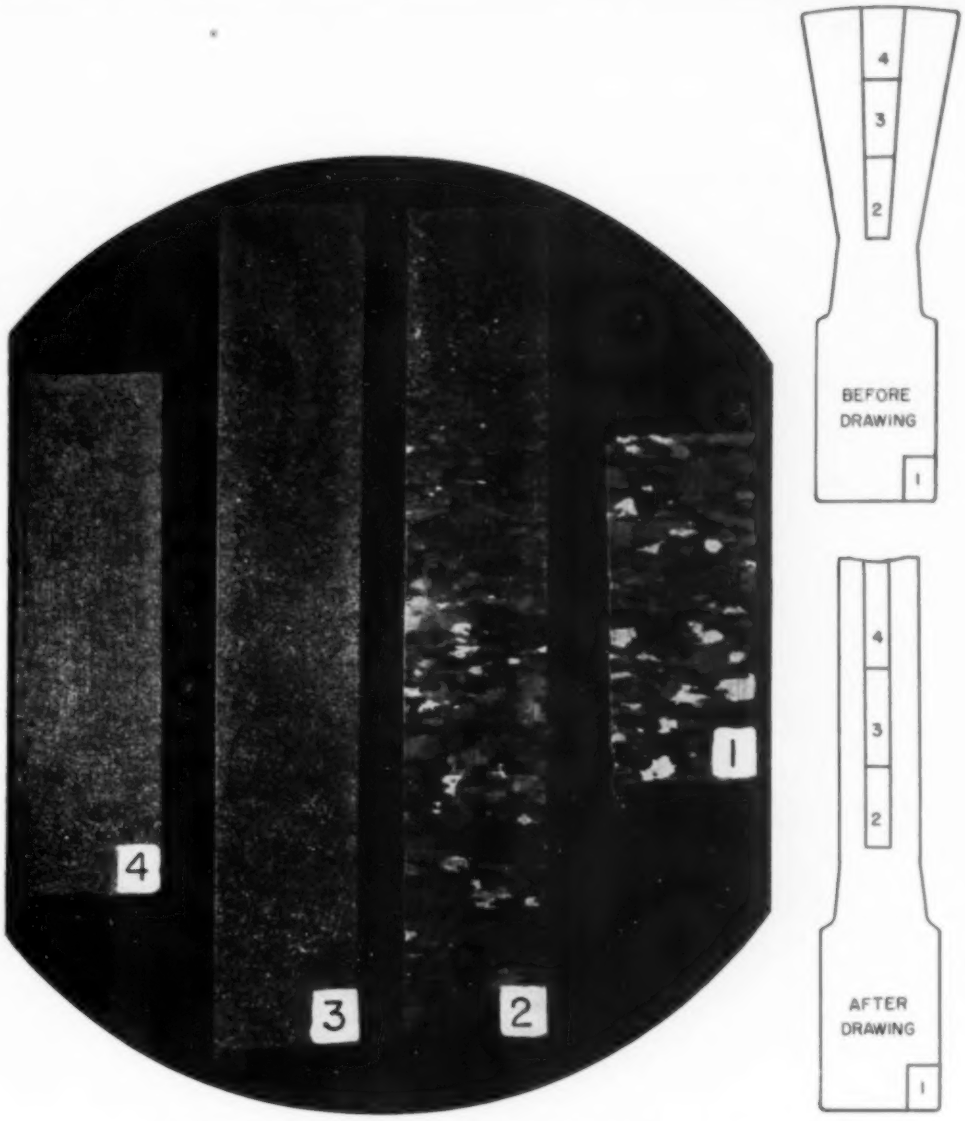


Fig. 1 — Wedge of Coarse Grained 24S-O Sheet Was Given a Solution Heat Treatment After Drawing. Regions near the throat retain original grain size; heavier reduction results in recrystallized metal. Note the relatively sharp transition

Other Factors for Study

It is recognized that the studies which have been presented in this and previous papers do not completely cover the effect of various factors which might influence the results, such as rate of strain hardening, effect of size and thickness of specimen used, and so on. Strain hardening properties are commonly said to be present in the 52S alloys, but do not seem to interfere with their ability for deep drawing. Size and thickness of the specimen will undoubtedly influence the results appreciably, and are being made the subject of further investigations.

It may be of interest to classify the factors of greater or less significance; they conveniently fall into three categories:

I. INHERENT PROPERTIES OF THE MATERIALS

(a) Grain size (already discussed)
(b) Microstructure
(c) Rate of strain hardening
(d) Allowable limits of local elongation in simple tension
(e) Cohesive strength and allowable strain in slip
(f) Susceptibility to notch effects
(g) Directional properties

II. CHARACTERISTICS OF THE FINISHED SHEET

(a) Process of chemical treatment and, hence, surface condition
(b) Variation in thickness

III. TEST AND PRACTICAL CONDITIONS

(a) Speed of drawing
(b) Friction and lubrication (already discussed)
(c) Influence of bending at draw radius (already mentioned)
(d) Effect of magnitude of throat radius r

Obviously, the investigation of all the before-mentioned factors is beyond practical possibility; furthermore, their effects may probably be of a minor nature, or of importance only in certain alloys. Temperature, and time at temperature, used in the heat treatment of aluminum alloys affect their microstructure, but the effect on drawing properties will probably be small. However, microstructure should be seriously considered when studying the drawability of steels, both carbon and low alloy.

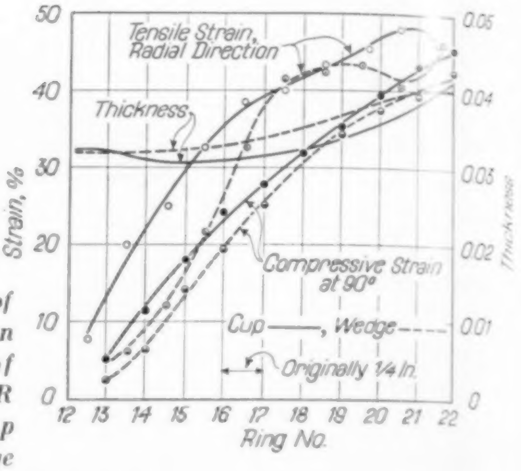


Fig. 3 → Comparison of Measured Strains in Drawn Cups and Wedges of 24S-O, 0.032 In. Thick. r:R ratio is 0.531 for the cup and 0.538 for the wedge

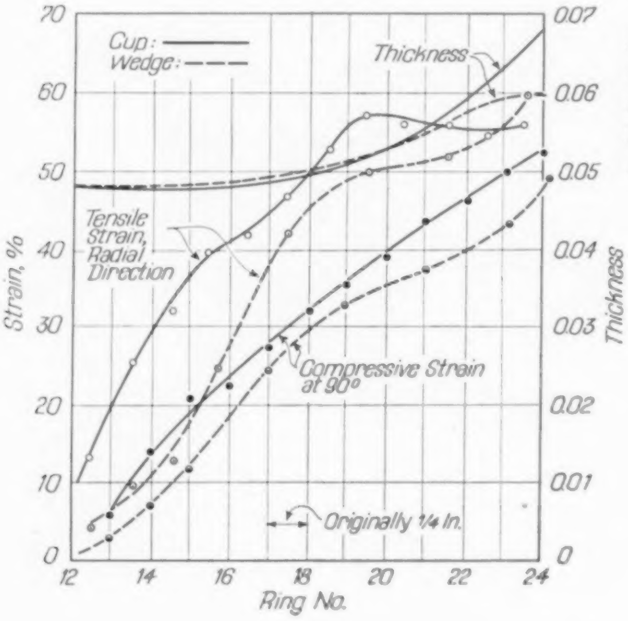


Fig. 2 ← Comparison of the Measured Strains in Drawn Cup and Wedge of 24S-O, 0.051 In. Thick. r:R ratio is 0.505 in both cases

A complex picture involving rate of pull (testing speed), hold-down pressure, *rate* of strain hardening and sheet thickness might be derived, were all the above factors taken carefully into account on alloys where they have an important effect. With steels, for example, the work of Winlock and Leiter (reported to the ⊕, *Transactions*, 1937, p. 163) on the extent of the strain and the course of the strain-stress curve in pure tension above the lower yield point, is sufficient indication of what may be expected. Contrary to preliminary findings for aluminum, it is necessary to control the *speed* of the test or the speed of hardening in order to achieve optimum results when stamping sheet steel.

In fact, it is possible that some generally accepted beliefs may have to be discarded or modified. For example, capacity for work hardening may not necessarily prove to be the best indication of deep drawing properties. Some such criterion as the ratio between the rate of hardening and the rate of deformation (which latter is related to the "local elongation" at fracture) may prove to be more important for some alloys.

The other factors are either related to those just discussed or are believed to be of minor importance, except that of surface condition and size effect. The surface condition is a very important consideration, perhaps not so much in alclad aluminum alloys as in other metals, ferrous and non-ferrous. The condition of the grain boundaries in such metals, as governed both by heat treatment and cleaning (pickling) operations, is very important in forming.

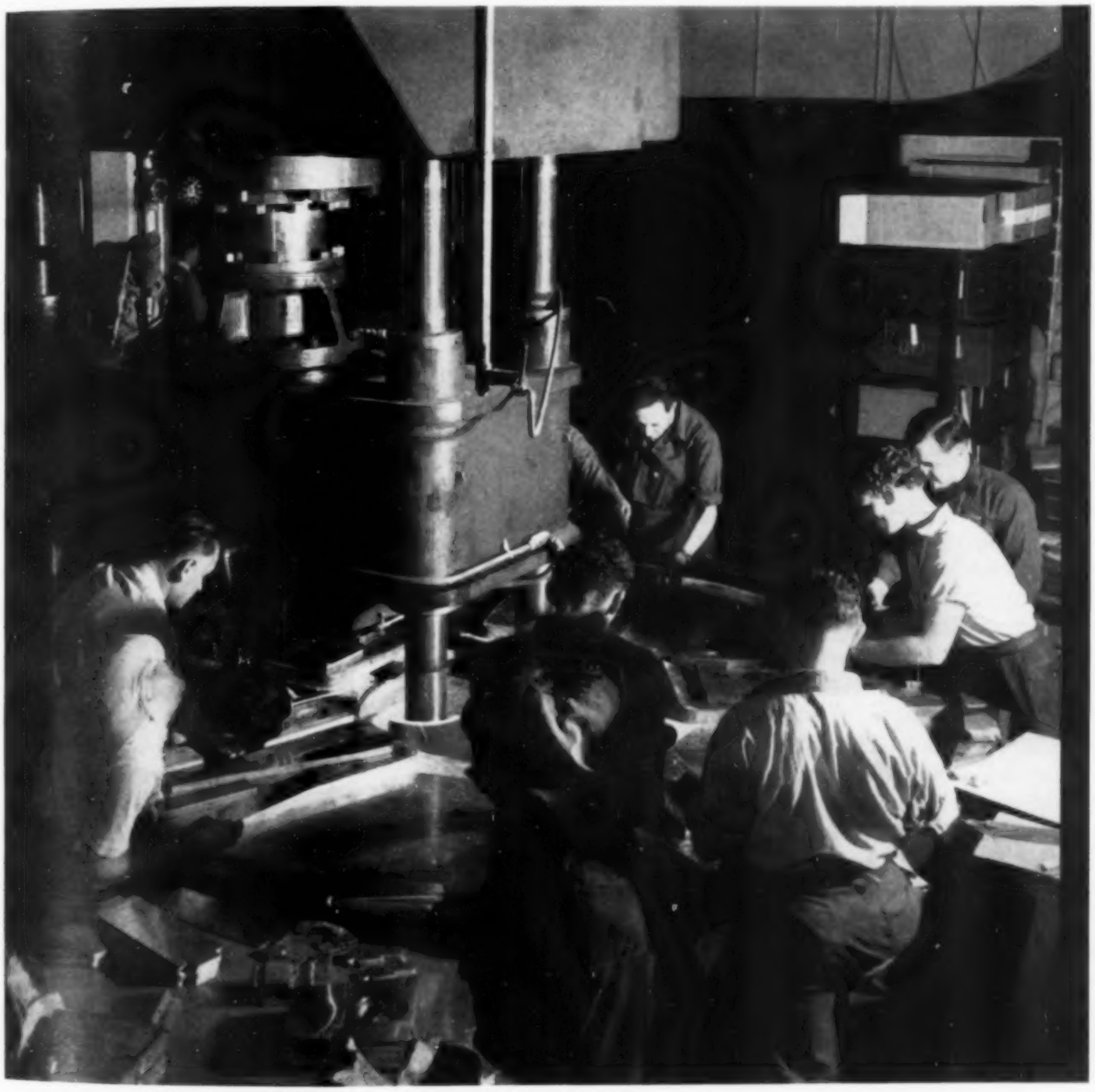
As for the size effect, it is known that the limiting drawing reductions are influenced by size of the work, being markedly more favorable when making very small parts, especially in the case of drawn boxes.

Correlation With Practice

At any rate, the studies we have presented for aluminum sheet have been sufficiently close to actual happenings, when deep drawing aircraft parts, that the feasibility of forming any particular part can be accurately predicted, and valid recommendations as to die design can be made. To substantiate this point Fig. 2 and 3 compare the strains as measured on a wedge-draw coupon and those determined from lines lithoprinted on a cup drawn at the same $r:R$ ratio. It will be noted that the general shape of the curves for tensile and compressive strain (ε_t and ε_c) was found to be similar in both cases, as were also the numerical values. The differences between the tension curves at the early part of the stroke may be attributable to the lack of bending over the draw radius, neglected in the wedge test.

A more extensive program of correlation between wedge and cup tests is now being conducted, utilizing other materials in addition to aluminum alloys. It is expected that a similar method of study will eventually be applicable to more complex shapes. Note that the same principles are involved in all drawing operations, and that many intricate shapes can be analyzed as consisting of sectors of cylindrical cups combined with straight (plane) sections.

Eventually it is hoped to develop a technique based upon laboratory tests, whereby a part may be analyzed in the design stage as consisting of combinations of cups, straight bends, shrink and stretch flanges, and the proper method and limitations of fabrication predicted on the basis of the fundamental data. Under these conditions a part would be released to the shop designed in such a manner that it could be readily fabricated without the necessity of subsequent design changes or excessive tool cost.



Rotary Table Centered on Side Columns of 250-Ton, Single Action, Hydro-Press. Designed by Lockheed engineers to speed production of small parts, eight men handle about 20,000 pieces per shift. After each "feeder" has placed one or more stampings on the form block, the table notches around one station. Centered on the press platen, the blank is pressed over the male form block by the thick rubber blanket attached to the upper platen

UP-GRADING OF SCRAP BRASS TO WAR USES

Part II of Report to OPM
by Advisory Committee
National Academy of Sciences

IN THE FIRST PART of the study of secondary copper which was requested by the Office of Production Management (and published in Metal Progress last month) a review of the statistics indicated that about one quarter of the secondary metal recovered in the years 1935 to 1940 inclusive had been put back into circulation by the electrolytic and furnace refineries; this was the cream of the scrap collections, both of new plant scrap and old discarded scrap copper (or "demolition metal"). About 50,000 tons a year was new scrap from the industry that fabricates unalloyed copper; it represents a fairly constant load of material in process. It will appear that much of this high grade metal absorbed by the refineries can now better be used, without refining, in the manufacture of needed composition ingot.

Existing statistics for total amount of secondary copper include sales of new plant scrap as well as demolition scrap (junk). The obvious fact was pointed out that the first category is a circulating load of metal in process; only the reclaimed junk represents a new supply of copper. It is, roughly, two thirds of the "total 2,857,100 tons secondary copper" reported in the statistics for the period 1935 to 1940, both years inclusive. Owing to the fact that a large proportion of this remaining 2,000,000 tons of old scrap is clean, choice grades absorbed directly by copper refineries, brass mills and non-ferrous foundries, the residue is increasingly hard to reclaim into usable composition ingot. It was also pointed out that the amount of junk that can be collected will decrease because there will be less and less new consumer goods to replace the discarded articles.

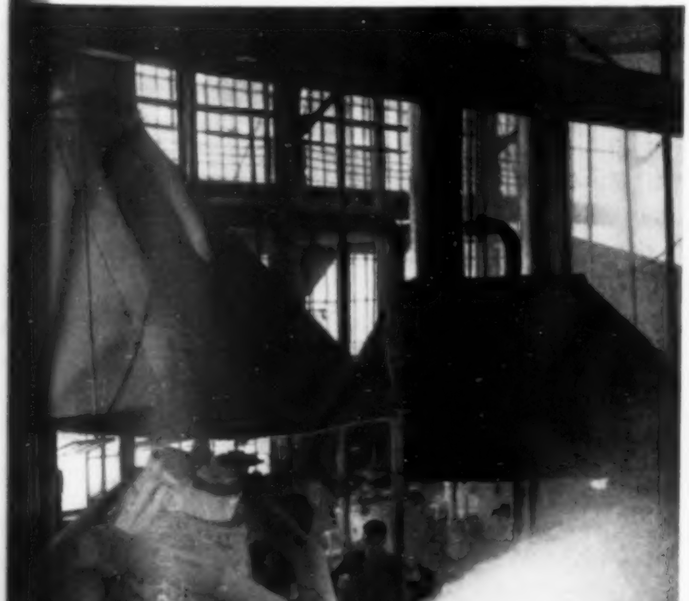
In the normal course of business, copper smelters, copper refineries, brass mills, non-ferrous foundries and non-ferrous ingot remelters enter the scrap market and purchase grades they can use profitably. The refinery, for instance, will buy No. 1 copper scrap when its price is enough lower than the price of electrolytic copper wire bar to warrant the handling and conversion cost, and impure No. 2 scrap when it is cheap enough to warrant electrolytic refining. The plumbing goods manufacturer can readily use scrap valves, faucets and pipe fittings when the price is slightly less than the cost of alloy ingot. The brass manufacturer can use No. 1 copper scrap to replace electrolytic cathodes in his furnace mixture; or if he can get new brass clippings or turnings from his customers that segregate their waste materials cleanly he can remelt them along with the crop ends and mill scrap he makes himself.

All the above are the choicer grades, both of new and old scrap. The rest of the secondary copper is the less desirable material on which the alloy ingot manufacturers' business has developed for the last 80 years. The problem of handling and disposing of the leavings is no new one to them. By proper selection of furnace charges, and by manipulation during melting, usable compositions have been produced. Most of the tonnage alloy contains a far larger amount of adventitious elements than would be there if virgin metal were used — see the data sheet "Standard Brass and Bronze Alloys of the Non-Ferrous Metal Institute" in Metal Progress for April — but in years gone by, foundries catering to numerous civilian industries have bought enough of this brass and bronze alloy ingot relatively high in incidental elements ("impurities") from the remelters to take much of the lower grade junk off the market. If the metal was too impure even for this it could be sent to a smelter and the impurities slagged off or volatilized.

In the present emergency the problem is fundamentally different. Much of the civilian market which consumes the low grade ingot has been eliminated by priority restrictions; the Government is now the big customer and its specifications almost always call for high grade ingot, quite low in incidental elements ("impurities"). The ordinary way for a remelter to make high grade brass or bronze ingot would be to select the scrap carefully and then melt with it a sufficient quantity of pure material (even No. 1 grade clean conductivity copper) to dilute the undesired elements. For a variety of suggested reasons this type of pure scrap for sweetening is not now readily obtainable, yet it is obviously more desirable to route clean copper scrap to remelters for such purposes than to send it to a refinery for purification and then have it come back to the ingot manufacturer.

Aside from seasonal influences (winter collections are always smaller than summer collections) the reason to expect shortages of good copper scrap is that normal sources are drying up. Buildings and residences (the most prolific source of small scrap) are not now being demolished at the ordinary rate. Interurban trolley lines, once a prolific source of old conductivity copper, are about all abandoned. Neither are obsolescent electrical equipment and transmission lines being dismantled; they are now being operated or kept in readiness to operate. (Anticipated copper scrap from the communications industry in 1942, for instance, is just half what it was in 1941.) A reduction in refinery output of pure copper from secondary metal is also to be anticipated in 1942. On the other hand, demands are greater, for, on Jan. 1, 1942, the remelters were making ingot at twice the rate of a year earlier, and current business is in the purer alloys needing a greater proportion of No. 1 scrap for make-up.

of the "Tea Kettle" Furnaces for Melting the 20 Tons of Non-ous Scrap Recovered Daily From the Westinghouse Shops



These facts, as well as the production statistics quoted in the former article, indicate that the shortage in good scrap is caused by a drying up of the supply and an increase in the demand.

Official orders have also seriously restricted the ordinary flow of good plant scrap into alloy ingot. Screw machine turnings, for instance, are no longer salable to scrap wholesalers or to ingot remelters; they must be returned either to the brass mill for remaking into more free-cutting brass rod, or if the turnings go to the ingot maker he is obligated to deliver to the brass mill an equivalent amount of usable composition ingot. If the alloy ingot remelter must convert it into the *same* nominal composition, he must use a considerable quantity of purer metal to counteract the contaminations it acquires in the manufacturer's machine shop.

In summary, it appears that impurities build up with each melting of material, and the supply of purer grades of copper scrap reaching the alloy ingot remelters will be shrinking at the very time when this industry is rapidly expanding and must produce an increased proportion of high grade (low impurity) composition ingot. To meet this situation it is recommended that enough of the unalloyed copper scrap and No. 1 old copper scrap be diverted to the remelters to meet the necessities of such compositions as "Navy grade" of composition ingot.

Uses of Composition Ingot

Production statistics based on data by the Non-Ferrous Ingot Metal Institute have already been shown in column 3 of Table II, June METAL PROGRESS, page 821. Figures acquired month by month indicate that the output during summer and fall of 1941 was relatively steady and at about twice the rate for 1940. On this basis the

1942 production of alloy ingot will be on the order of 300,000 tons, and will contain (at an average of 80% copper) a little under 250,000 tons of copper.

A special study was also made of the uses, by analyzing shipments of remelted ingot for August, September and October 1941. These figures, extended to the entire industry in terms of ingot weight (not copper contained) represent a good guess as to the situation during the third quarter of 1941. The figures even now have more than academic interest, for they represent clearly the changes from "business as usual" and indicate some of the new problems that must be met.

Estimated Consumption of Alloy Ingot for the Year 1941 Based on Data for the Third Quarter

Fire fighting equipment	10,000 tons
Valves and fittings (plumbing)	78,000
Lawn hose nozzles, etc.	1,000
Farm machinery and implements	5,000
Electrical equipment	5,000
Elevator equipment	1,000
Dairy machinery	4,000
Builders' hardware	4,000
Meter equipment	8,000
Bearings and bushings	26,000
Railroad and locomotive equipment	29,000
Marine equipment	5,000
Army and Navy castings	71,000
Pump castings	8,000
Mining machinery	7,000
Machine tools	3,000
Automobile parts	4,000
Miscellaneous castings	31,000
Total	300,000 tons

The essential nature of many of these items is apparent at a glance; all of them are now under priority control. Substitutes (plated or protected steel) for many items have already been worked out by enterprising manufacturers. Furthermore, the trend away from civilian production into material for ships and the armed services is by now almost complete. Even plumbing goods is restricted to cantonments, war plants, shipping, small houses, and repair parts. Therefore it is better to discuss the problem of supply for essential services in its broad aspects rather than item by item. This can be done by taking the three major items in the above table:

Plumbing; 78,000 tons, representative of yellow brass.

Bearings, bushings and railroad equipment; 55,000 tons, representative of the leaded brasses and bronzes.

Castings for Army and Navy; 71,000 tons, representative of bronzes with low impurities.

The first item, involving the problem of up-grading of leaded brass will now be discussed, leaving the two other items for a subsequent installment.

Up-Grading of Leaded Brass

The question, baldly put, is this: "If we are restricted in the manufacture of yellow brass castings (and they are largely consumed by the building industry), what can we do with the large amount of lowest grade scrap that is collected from discarded articles and demolition operations?" A representative alloy, conforming to many current specifications, is nominally 71 Cu, 1 Sn, 3 Pb and 25 Zn. The lead is there because the zinc which was used to make the alloy in the distant past was in all probability "prime western" containing up to 1.50% of lead, because it is far more persistent than the rather volatile zinc and tends to increase on each remelting, because much copper and brass (like automobile radiators) available to ingot remelters is covered with solder, and lastly because it improves the machinability of the part without detracting from its castability or necessary physical properties where pressures and temperatures are moderate.

Now assume that a large surplus of leaded yellow brass ingot or scrap accumulates unused, as a result of restrictions on civilian consumption. (In normal times consumption of leaded yellow brass is so large in proportion that some 4500 tons of new pig lead is used annually by the foundries in compounding new alloys.) What can be done with this leaded yellow brass scrap? Could this casting alloy, which has a broad tolerance for adventitious elements, be converted by simple alloying to one of the compositions for rolling, where impurities must be held to narrower limits else cracked edges and poor surfaces result?

Consider one of the least pure of these rolling mill alloys, free-cutting rod. The compositions are as shown in the tabulation on top the next page.

If we assume that median amounts of elements marked — were present in the cast brass it would require dilution with 3½ times the weight of 99.75% pure copper and zinc to bring the impurities down to that tabulated by this rather impure rolling mill material, whereas if the casting brass hugged the high side of the specification it would require dilution with six

Cast Versus Wrought Material

	Leaded Yellow Brass	
	Casting Ingot	Free-Cutting Rod
Copper	70 to 71.75%	60 to 63%
Tin	0.75 to 1.5%	—
Lead	2.50 to 3.5%	2.50 to 3.75%
Zinc	25% nominal	
Nickel	0.50% max.	—
Iron	0.50% max.	0.15%
Antimony	0.10% max.	—
Sulphur	0.05% max.	—
Aluminum	none	—
Silicon	0.05% max.	—
Phosphorus	0.01% max.	—
Total of all others	—	0.50% max.

times its weight of pure copper and zinc. Obviously, it would be far better to start off with ingot copper, zinc and lead rather than surplus casting ingot if we need more free-cutting brass. The impossibility of "up-grading" by dilution is even more obvious in the case of other rolled brass products, where lead is ordinarily held to 0.10% max.

In the remelting of old scrap a certain amount of refining is permissible by an oxidation process (blowing the bath with air). This is most effective in reducing zinc; some lead also goes, but the iron, aluminum, and silicon stay. Blowing in a hearth furnace must be done with care, for the slags are very corrosive and they carry off much valuable copper. Unfortunately lead stays behind more tenaciously, and leaded yellow brass cannot be up-graded much in the remelting furnace. Exceptions to this statement are the blowing of low lead brasses into alloys similar to Navy "M" metal (88Cu, 6½Sn, 1½Pb, 4Zn) and into ingot suitable for yellow brass die castings, now being used to a certain extent for munitions.

Normally, when such high zinc alloys are handled by remelters they are balanced against high lead bearing metal and sweetened with high tin solder or tin ingot to make alloys of the 85% copper, 5% tin, 5% lead and 5% zinc class. It is believed, however, that future collections will produce far more high zinc material than can be disposed of in this way, and its prompt utilization will require smelting and separating into its constituents.

The problem of smelting the impure brass is much like the problem of smelting the even more impure metals originating in the secondary industry. It can be and is done on a limited scale by complicated oxidation methods. It would be difficult to provide smelting capacity for possible surplusses on the order of 100,000 tons a year. There are some alternatives, but they are wasteful of valuable metal. It is reminiscent of the problem of handling the abundant copper-lead-zinc ores in the West prior to the discovery of differential flotation process for separating the minerals prior to putting them into a furnace. Blast furnacing the original ore was uneconomical despite many strenuous efforts to do so; usually, what resulted was a lot of zinc-lead fume, a sticky zincky slag, low grade copper matte and speiss, and some lead leaking through the furnace bottom. Even yet the problem of recovering all mixed values is very difficult. Zinc at a lead or copper smelter is eliminated in fume (which is valuable when caught) and in slag which is lost. Lead in a zinc ore volatilizes with the zinc and contaminates the spelter. Most lead in a copper smelter is lost with the zinc.

Plant now exists wherein a considerable amount of brass could be bessemerized with copper matte in a smelter equipped with a good dust collection system; the lead-zinc fume is a de-graded by-product acceptable to lithopone makers*, and the metallic lead and tin remaining alloyed with the blister copper would eventually lodge in the tank house slimes. One difficulty is that the large copper smelters are a long distance from the scrap centers; however, there are at least three relatively small plants (say of 20,000 tons per year capacity each) in the East capable of doing such work.

Conclusion

Since typical large remelters normally ship at least one quarter of their alloy ingot to plumbing goods manufacturers, and since large plumbing goods manufacturers also buy scrap freely for compounding in their own foundries, yet at present only about one tenth of this product has any priority rating, it is believed that a quantity of "orphan" brass (high zinc alloy) is to be anticipated. Especially will this be true after any intensified scrap collection. It is recommended that a study be made of the problem of reclamation, which means separation of the metals to a purity *consistent with excellent recoveries* of the four valuable metals copper, zinc, tin and lead. Methods are available but plant capacity may be lacking.

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*Rather than de-grade the product into lithopone, it would probably be better to use fume and residues in electrolytic zinc and electrolytic solder manufacture.

BITS AND PIECES

Metallurgicus' Own Page

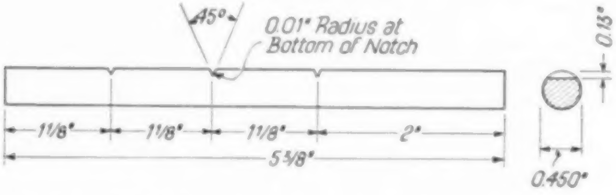
WHY NOT a page in METAL PROGRESS called "Bits and Pieces" or "Save the Scraps" or "Chips From the Metallurgical Log" or "Information, Please" or something, to print odds and ends of laboratory results and improved plant practices that would otherwise rest in some notebook or even go unrecorded?

For example — but the first example is printed below.

Contributions are solicited, nay urged! METAL PROGRESS, I am informed, will reward the author of each acceptable item with a book — *any* of the books of the ⊕ book list, other than the Handbook. METALLURGICUS

Cheap Izod Test Piece

A FEW YEARS AGO I had a problem in hand which required a series of Izod notch-bar tests. However, the cost of machining the standard 3-notch 0.394-in. square bars was prohibitive (remember the depression?), while the 0.450-in. round 3-notch bar shown in the sketch looked very attractive for cost (rough turn, centerless grind, mill notch). So a series of comparative tests was run, with the results shown in the table. Special jaws had to be made for the testing machine, of course, but results looked good enough to warrant subsequent use of the round test bar for non-scientific work. The material was cold drawn S.A.E. 3140, $\frac{9}{16}$-in. round. It was quenched from 1500° into oil, and drawn 1 hr. as shown. (METALLURGICUS)



TREATMENT	ROCKWELL HARDNESS	IZOD, FT-LB.	
		0.394 SQUARE	0.450 ROUND
As received	20 to 23	21.5-21-21.5	17-18-18.5
Quenched, no draw	C-55	2-2-1.5	1.5-2-1.5
Drawn at 300° F.	53.5	3-4-3	5-3.5-3.5
550	49	6-8-6	5.5-5.5-5
650	44	10-10-10	10-9-10
750	42	23-22-19	20.5-21-21.5
800	39	37.5-37-37	41-41-41
850	37	41-44-45	41.5-40-39
925	33.5	59-58.5-59	56-57-57
1000	31	69.5-65-70.5	62-65-60
1075	25	76-74-80.5	77-85.5-82.5
1150 *(a)*	23	85-88.5-92.5	89-96-98
1150 *(b)*	23	87-86-91	88-94-85

(a) Water quenched from draw; *(b)* furnace cooled.

Magnetic Inspection of Cylinders

CYLINDRICAL PARTS, small ones like bearing races, and larger, longer ones as well, can be adequately inspected for metallurgical uniformity by using a standard oscilloscope, a synchronous motor driving a suitable chuck, and a scanning device consisting of a simple electromagnet — an alloy bar surrounded by a coil. In the test the part is first demagnetized completely, next chucked and rotated at high speed around its axis of symmetry, and at the same time strongly magnetized so that the flux extends outward from the surface being tested. Finally this flux is explored by bringing the electromagnet near the rotating piece. If there are any flaws, hard spots or other defects in the piece, they will cause the magnetic field to vary, and such variations induce a voltage in the exploratory coil, which is amplified and indicated by means of the oscilloscope. The test piece is rotated synchronously with the cathode-ray sweep, so that a uniform field is traced on the screen as a luminous straight line, but faults show up in the oscilloscope trace as dips. A second trace on the screen acts as a reference line and shows marks corresponding to 30° angles around the test piece. By this means a fault can be spotted to within a few degrees. (C. S. WILLIAMS, Westinghouse Research Laboratories, East Pittsburgh.)

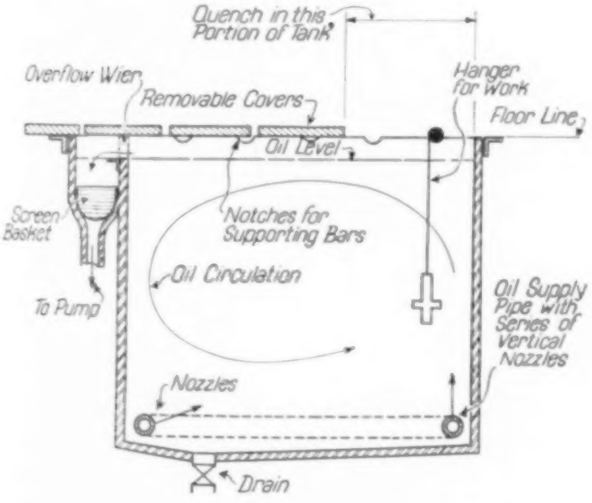
Case With Controlled Carbon

HIGHLY STRESSED alloy steel parts are given high surface hardness without excess carbides and corresponding low fatigue resistance in the following manner: Carburize to correct depth, whereupon the surface carbon is about 1.20%.

Next the piece is copper plated for surface protection, and heated a little above the critical long enough to diffuse the carbon inward and convert the surface to eutectoid structure (carbon about 0.65%). Oil quenching such a piece retains so much soft austenite that to acquire the maximum of Vickers 800 the quenched pieces are refrigerated in dry ice and alcohol, and the fully transformed structure is then tempered. (Sound metallurgy observed by THE EDITOR in the ordnance works in Shangri-La.)

Tank for Oil Quenching

QUENCHING PRACTICE can be much improved by using large rectangular tanks, generous overflow of oil and a swirling motion in the quenching liquid. A tank for a moderate sized furnace would be about 6×6×5 ft. deep and contain 1200 gal. of oil, thus having a high heat capacity. A wier, 6 in. lower than the top edge, occupies half the rear lip, giving ample space for surges or waves of oil to spill over into a trough leading to the circulating pumps. Oil enters in pipes forming a single closed turn; these are perforated so the oil is jetted as shown in the sketch, setting up a circular swirling motion in the entire tank. The oil sweeps up against metal being quenched, and then across the top toward the overflow at the back, thus giving hot oil and carburizing compound the best chance to fall into the overflow. Much work is quenched by hanging on hooks or tongs from a single rod across the front of the tank. When the rod is full it may be moved to another notch nearer the wier and replaced by another. (WM. J. DIEDERICHS, metallurgist, The Autocar Co., Ardmore, Pa.)



WELDABILITY

of Substitute Steels*

By A. B. Kinzel

THE PROBLEM of predicting weldability has long been with us and has been particularly tantalizing in that if all the conditions were quantitatively known weldability could well be predicted. This applies particularly to the effect of the welding temperature cycle on the steel adjacent to the weld.

A method for handling readily obtainable data on this phenomenon so as to arrive at a definite conclusion on weldability was proposed by the writer last fall in an article entitled "The Specification of the Weldability of Steels" in Research Supplement to *The Welding Journal*, October 1941, page 483-S. This method dealt with the universal case on a basis of absolute measurements and was necessarily complex.

In dealing with a specific instance the method becomes relatively simple and quick. Such a specific instance comprises a steel being satisfactorily welded in a joint of specific geometry by a specific process and technique and a specific steel intended to be used as a substitute in the same application. In other words, results need be purely relative and comparative.

There follows a list of steps necessary to arrive at this comparison. In this list "standard steel" denotes the steel being regularly welded, and "new steel" that under investigation.

1. Section the joint made in the standard steel and determine maximum hardness next to the weld by Vickers or Rockwell tester.
2. Run a Jominy end-quench test on the standard steel after heating to 1700° F., and determine the distance from the end at which the hardness is the same as that established in Item 1. (While the standard Jominy bar is preferred, any bar of reasonable cross section, such as ¾-in. square or ½ × 1 in. cross section may be used.)
3. Heat three strips of the standard steel to

(Continued on page 136)

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*A contribution to the Welding Research Committee's Monthly Report, in supplement to the *Journal* of the American Welding Society, June 1942, page 286-S.

Photos by Bourke-White for Aluminum Co. of America

More Aluminum for More Aircraft — More, More!

EXPANDING AMERICA'S ALUMINUM CAPACITY BY 650%

By Thomas D. Jolly
Chief Engineer and Director of Purchases
Aluminum Co. of America

UNDER PRESENT CONDITIONS, most of us have our noses so firmly pressed against our own grindstones that our range of vision doesn't extend much beyond our own jobs. Because this is true in my own case, this address (delivered before the National Association of Purchasing Agents) will not be a scientific paper but simply a recital of our experience during the past two or three troublesome years — in other words, some notes on the expansions in the aluminum industry and, in particular, in Aluminum Co. of America.

Two months after the Munich conference of 1938, the Aluminum Co. of America initiated a study of its ability to meet any demand which might come from Britain or France, should war suddenly break out. A six-man committee, representing various departments within the company, was appointed. That committee made frequent reports to the management as conditions changed throughout 1939. Based on these reports, and disregarding both the large stock of aluminum on hand and the apparent small requirements of the armed forces of this country, we inaugurated an expansion program which, with the additions since made to it, calls for a capital expenditure of about $250,000,000 of the company's money. This expansion is now substantially completed. The various steps that led to its formulation are as follows:

On February 12, 1940, the Russo-German economic treaty was signed, and on March 8 we started construction of a plant to produce 30,000,000 lb. of aluminum ingot per year. A month later, Germany invaded Denmark, and on April 16, 1940, we decided to increase our new plant to 60,000,000 lb. capacity.

On September 1, 1940, our National Guard units mobilized; on September 3 the Navy Department announced the transfer of 50 United States over-age destroyers to Britain in exchange for air bases; while on September 14 the compulsory draft bill passed. With the United States embarked on a defense program, we again increased the size of the new plant — this time to 160,000,000 lb. of new capacity.

Other aluminum metal-producing plants were expanded to the limit of the power available, and two new hydro-electric power developments were also started. Mining operations, ore refining and fabricating facilities kept pace with these increases in ingot-producing capacity, and continued to expand as the defense program developed. But both the funds and credit of any privately owned industry are limited, and by midsummer of 1941 it was quite obvious that no company could finance the full requirement of aluminum.

On August 19, 1941, we signed a contract with Defense Plant Corp. (a governmental agency) to design and construct at cost, but without fee or profit to the Aluminum Co. of America, one ore refining plant and three aluminum metal-producing plants. By a supplemental agreement of December 12, 1941, we agreed to build two additional metal-producing plants, five in all.

Months before any contracts were signed, we became convinced in our own minds that these additional government aluminum plants would have to be built and that we would have to build some of them. Accordingly we obligated the company for something over $16,000,000 worth of equipment to be used in their construction. This enabled us to save many weeks; two of these metal-producing plants are now in operation; three others will come along in the very near future. We have now started on a new program for Defense Plant Corp. Censorship rules do not permit us to disclose the type, capacity or location of new plants, but we can say that we are building, for Defense Plant Corp., a total of 15 plants and that they are located in eight states. With our own program, this gives us a total of 35 major projects now under way. These bring our total acreage of floor space put under roof since January 1, 1940, to 335 acres.*

By May 2 of this year, we had placed 108 sub-contracts for Defense Plant Corp., only eight of which were negotiated; 400 bids were obtained for the 100 competitively awarded contracts, and of course there are still quite a few not closed. On May 2 we had 7920 men engaged directly on construction and had placed 17,500 purchase orders.

Summing up: By the end of 1943, the United States' annual production capacity for aluminum ingot will be approximately 2,100,000,000 lb. — 6½ times its 1939 production. Each of several of the new plants will produce more aluminum than the entire nation made at its World War I peak — and still there will not be a pound available for civilian use!

How much is 2,100,000,000 lb. of aluminum? It is sufficient to rebuild every railroad passenger car in the United States three times a year. Or it could be utilized, were we not at war, to put a 30-piece cooking utensil set in every one of America's 34,000,000 homes, with enough metal left over to make 5,000,000 miles of aluminum transmission cable of the type used for the electrification of rural America.

It might help to understand the purchasing and construction problems involved if we rather briefly review the processes employed in the production of aluminum.

Chemical Purification of Ore

We start with a mineral called bauxite, which contains about 55% aluminum oxide and less than 7% silica. Bauxite is ground to a fine powder and digested in a hot caustic solution under pressure. The aluminum hydrate is dissolved in the hot caustic liquor and passes with it through a filter press, leaving the insoluble material in the bauxite ore, commonly called "red mud", to go to waste disposal. The liquor is then cooled and passes into large tanks, where aluminum hydrate is precipitated. This is washed to remove entrained soda, thickened to remove excess water, then calcined and shipped to the reduction plants as alumina (Al_2O_3). This ore refining process requires large quantities of pure water, steam, soda ash and lime, as well as 2 lb. of bauxite for each pound of alumina produced.

The alumina, or aluminum oxide, is reduced to metallic aluminum in the metal-producing plants in long rows of electrolytic cells. The cell consists of a steel shell lined with carbon, which serves as the cathode. Electricity is led into each cell through carbon anodes suspended from above the cells on overhead busbars.

In the operation of the cell, the aluminum

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*The following statement was released on May 30 by A. H. Bunker, chief of the Aluminum and Magnesium branch of War Production Board:

"Three new Government-owned aluminum plants have started operations so far this month, a fourth is expected to begin production early in June and the entire first expansion program of seven plants will be in production by August 1. All seven plants will be completed ahead of schedule. The first two were finished in six months, as compared to a normal building time of 11 months. The plants will get into full production from 60 to 120 days after completion, depending upon size.

"The completed plants are located in Oregon, Washington and New York. The Alabama plant will be completed next, followed by ones in Arkansas, California and a second plant in Washington, in that order. All were built for the Government by the Aluminum Co. of America, which also will operate the plants.

"Plants in the second expansion program, also of 640,000,000 lb. annual capacity, will start coming in about December of this year. The flow of aluminum metal is expected to increase every month from now on until the early part of 1943 when the entire aluminum capacity as planned by W.P.B. will be operating at its peak."

Wide Sheet (Strip) Is Edge-Trimmed, Sheared to Correct Width and Coiled Simultaneously

oxide, dissolved in a bath of molten cryolite, is decomposed by the passage of the electric current. Cryolite is found in commercial quantities only in far away Greenland; however, we have facilities in this country for making a synthetic material which is the chemical equivalent of natural cryolite, and we can use either. At the present time, additional electrolyte plants are being built so that we will be entirely independent of Greenland cryolite.

Bath material (cryolite) is first introduced into the cell. When it has been melted by the electric current, alumina is added to the bath and dissolves in it. The low voltage direct current separates the aluminum oxide into aluminum and oxygen. The oxygen liberated during the reaction combines with the carbon anode to form gas, which escapes, while the aluminum is deposited on the bottom of the carbon-lined cell (the cathode) where it remains as a molten layer until tapped off. As the bath becomes exhausted in alumina, more alumina is added and the cycle of operation is repeated.

In the production of 1 lb. of aluminum metal, 2 lb. of alumina — made from 4 lb. of bauxite — is consumed. In addition, 10 kw-hr. of electricity is required to separate the aluminum from the oxygen, and 0.75 lb. of carbon electrode is burned. In fact, if we take into account all the materials used in the different steps, from the mining of the ore to shipment of metal, we find that 9 lb. of raw material is required to make 1 lb. of aluminum.

Carbon electrodes are an important item. They are made by forming a hot mixture of coal-tar pitch and calcined petroleum coke in molds under hydraulic pressure. These electrodes must then be baked to remove the volatiles from the binding material, and after cleaning they are ready for use. Such large quantities of carbon electrodes are consumed in the aluminum industry that it is necessary to provide facilities for their manufacture nearby the metal-producing plants.

The major item of consideration is, of course, electricity. For every dollar we have invested in plant and equipment at our large Tennessee Works, for example, there is another dollar invested in the mountains in hydro-electric plants and, in addition, we are drawing power from the Tennessee Valley Authority as well. To produce aluminum at the 2,100,000,000-lb. rate in 1943 will require annually more electricity than was consumed in 1940 in 27 of the 48 states. Yes, the aluminum industry in one *day* will draw more current than a city of 60,000 homes consumes in one *year!*

Provision of this large amount of electricity has required considerable planning and investment in power developments. Power comes from three main sources — *(a)* company-owned hydro-electric plants; *(b)* hydro-electric plants owned by the government; *(c)* steam and water power plants of privately owned public utilities.

It is interesting to look back and see how the conditions of supply have changed in the comparatively short time we have been engaged in this expansion program. It started before we even thought of serious shortages of materials; then came the defense program and voluntary priorities on some materials. Then, as defense plans developed, so did mandatory priorities — and, I might add, we can well appreciate the meaning of priorities, since the aluminum industry was the first to be placed on priorities! Then came allocations, restrictions, and prohibitions on the use of materials, and frozen price levels.

At the outset, when only the expansion program of the Aluminum Co.'s own plants was involved, it was cheaper and quicker to expand existing plants (and, where possible, to build new plants near old ones). In that way we could utilize the supervision and experience of existing personnel. Today we are building an aluminum industry seven times the size of our peacetime industry and that spreads our personnel pretty thin.

New Sites in Populous Centers

The first Defense Plant Corp. sites were selected four to six months before Pearl Harbor. The then Office of Production Management recommended the general locations after a study of markets, source of raw material, power and labor. The actual sites were then selected on the basis of accessibility, foundation conditions, and surroundings. Such a plan of selection is no longer feasible because of the enormous quantity of power required and the shortage of materials. It has therefore been necessary to locate the new plants so as to consume the least possible amount of copper in transmission lines. This is contrary to the old theory that it is best to locate aluminum plants in sparsely settled areas where a plentiful supply of power is available at low prices, the power being cheap principally because there are few if any customers. Under present conditions, there is a greater amount of power instantly available in the large metropolitan districts than in any other, and that is where the new electrometallurgical industry is being built. Since it has been officially released, it is all right to say that the largest aluminum metal-producing plant in the country is now under construction about ten minutes by automobile from the Waldorf-Astoria hotel in New York City.

A unique feature of this plant will be its pure silver busbar and silver-wound transformers. The Conservation Branch of W.P.B. solved our copper purchasing problem by arranging this substitution. The government-owned metal-producing plants require about 36,000 tons of copper busbar. If we add the requirements for light and power wiring, motors and other miscellaneous uses, this becomes entirely too much copper for these days of heavy military demand. On the new program, the U. S. Treasury will loan Defense Plant Corp. the silver from the vaults at West Point. It will be fabricated by the copper companies and shipped to us ready to install. Present plans call for the use of about 13,000 tons for heavy busbar. At the end of the emergency it is to be returned to the Treasury.★

Before the Aluminum Co. of America started building for the government, we decided that it would be necessary to standardize buildings and equipment as much as possible in order to complete our construction and obtain production as soon as possible. This has paid big dividends, not only on our work, but has spread out and benefited many people who never heard of us. For example, we have purchased since January 1, 1940, 175 cranes from one crane manufacturer, all of the same span and capacity. The only change in specifications for any of these cranes was on a few motors to run on 50-cycle current. Thus, the crane builder was able to set up a production line, and claims 50% better efficiency than if he had the shop filled with cranes built to miscellaneous specifications. Likewise the foundries supplying castings and all of the other suppliers were able to produce more because of the duplication.

We bought 72 buildings from the same shop drawings, but the most interesting duplication is in one of the powerhouses, where we needed 85,000 kw. more power. No amount of standardization will obtain quick delivery of two 35,000-kw. steam-driven turbo-generators. We were to be supplied with temporary power until we could get a steam power station in operation, but because of the long *(Continued on page 100)*

★Editor's Note — The idea of utilizing some of the U. S. Treasury's hoard of 85,000 tons of "free silver" for the massive busbars conducting the low-voltage current to aluminum and magnesium pots in the new government-owned plants apparently occurred to several engineers more or less simultaneously. For instance, it was contained in a memorandum on the conservation of copper dated Nov. 12, 1941 by the Editor and addressed to the Metals Conservation and Substitution Group of the National Academy of Sciences. The idea was apparently much more acceptable to engineering than to Treasury and political experts, for not until mid-May were the details finally arranged for a loan of up to 40,000 tons of silver, and then after insistent efforts of Harvey A. Anderson of the Conservation and Substitution Branch of W.P.B.

THE ELECTROLYTIC POLISHING OF BRASS AND COPPER

By G. J. Foss, Jr.
Lieutenant (junior grade) U. S. N. R.
and Larry Shiller
Ass't Mechanical Engineer
Metallurgical and Testing Section
Naval Gun Factory, Washington, D. C.

SINCE the introduction of the lend-lease program and our preparations for the war in which we are now engaged, many civilian industries have begun production of brass cartridge cases of all sizes. Some of the companies so engaged have had little or no experience in brass metallography. It is, therefore, timely to review one of the best and simplest processes — the electrolytic process — for preparing a cartridge brass specimen for metallographic examination.

In the conventional method of preparing a brass specimen for metallographic examination the material is first cut to size and usually mounted in a plastic mold. The specimen is then carefully filed to remove the cold work and rough edges produced by milling or sawing, and then rubbed on a series of polishing papers in succession ending with a 000 paper, either dry or lubricated with soap or graphite. Finally the specimens are polished on wet, cloth-covered wheels on which suspensions of various grades of aluminum oxide or sifted magnesium oxide are used.

This hand method requires considerable skill and time, and leaves a layer of flowed metal with non-uniform etching characteristics, particularly when the metal is soft. Further, the size and shape of the specimens are usually limited by the size of the plastic mount and by the fact that unmounted specimens of odd shapes cannot be conveniently held steadily against the wet, cloth-covered wheels.

In the electrolytic polishing method the size and shape of the specimen can vary considerably, depending upon the range of the meters and rheostats and the direct current source available. If the surface is smoothly filed after milling or sawing, the electrolytic polishing will remove all traces of surface metal which has been mechanically worked.

Technical details and the theory of electrolytic polishing have been described by P. A. JACQUETT and W. C. ELMORE (summarized in METAL PROGRESS for December 1939, page 771, and January 1940, page 55). We have satisfactorily used aqueous solutions containing 25 to 55% of commercial ortho-phosphoric acid (85% H_3PO_4) as the electrolyte. The arrangement of the successful bath and the electrical circuit used

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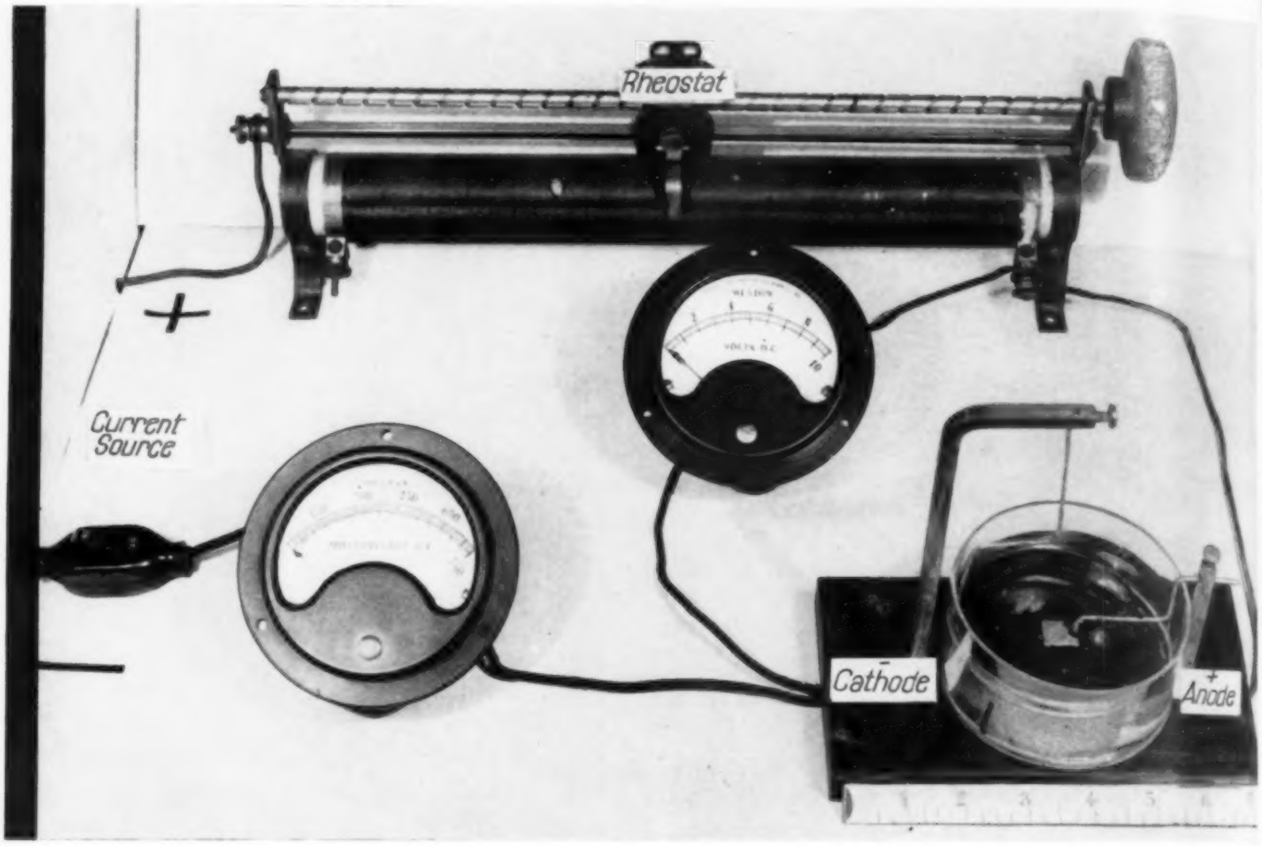
This article has been read and approved for publication by the Bureau of Ordnance, Navy Department, Washington, D. C. Opinions and assertions are those of the writers, and are not to be construed as official or as reflecting the views of the Navy Department.



Simple Set-Up of Electrolytic Polisher, Showing Cell (4-In. Dish) in Series With Rheostat, Milliammeter and Switch, and Voltmeter to Measure Potential Across Cell

at the Naval Gun Factory is shown in the photograph above.

For best results the surface to be polished should be horizontal. Some investigators have indicated that the cathode surface should be above and parallel to the anode surface being polished, but our investigations indicate that the position of the cathode does not particularly influence the results. A vertical cathode of the general shape of the dish containing the electrolyte may be used; such an arrangement facilitates the removal of the specimen from the bath. The cathode should be located from ½ to 2 in. from the anode and should have at least 10 times the surface area. Both anode and cathode can be made from brass or copper.

The sketch shows the general form of the current-voltage curve for an ortho-phosphoric acid solution. It consists of several distinct sections. Up to point C, metal is removed from the anode without any noticeable brightening of the anode. From C to C' a noticeable drop in current occurs, and anodic brightening begins. From C' to D anodic brightening continues with very little change in current density, but considerable change in voltage. At D the current increases sharply with little change in voltage and a noticeable evolution of gas. Gas bubbles adhere to the anode and protect it from further anodic action, leaving the surface marred by numerous unpolished points or dots in relief. At current densities about 10 times that necessary for anodic brightening without gas evolution, a bright surface is again obtained since gas bubbles are produced so rapidly and in such quantity that they do not adhere to the surface.

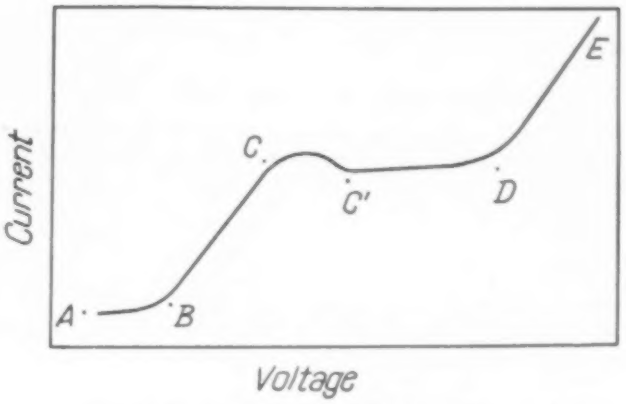
It must be remembered that the voltage and not the current is the controlling factor in the electrolytic polishing process. For new, non-agitated solutions with electrolyte concentrations of from 55 to 25% ortho-phosphoric acid at room temperature, a copper anode about 2 sq.cm. and a horizontal cathode above the anode, the voltage ranges for the various points on the curve are approximately as follows:

C = 0.7 to 1.0 volts
C' = 1.1 to 1.3
D = 1.7 to 2

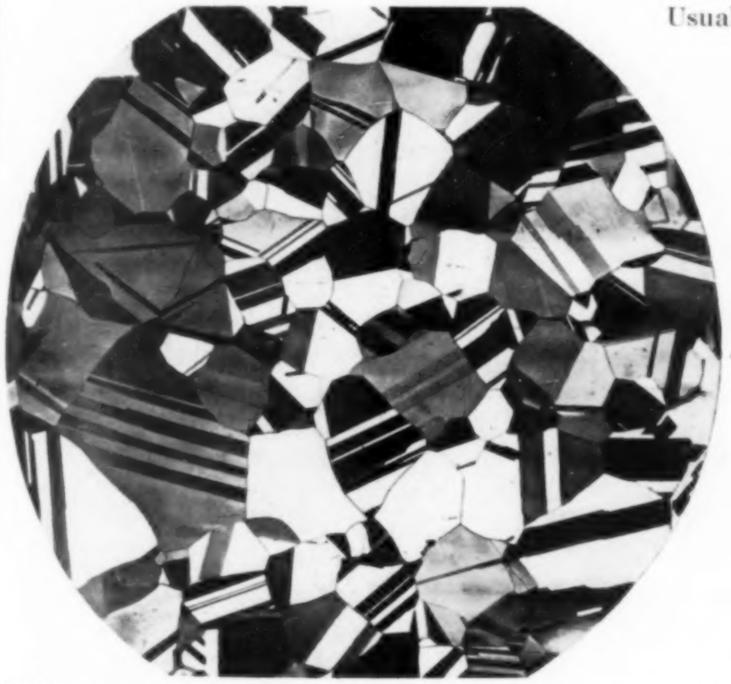
When the solution is new some difficulty is encountered in holding the voltage at a desired value. However, as soon as the electrolyte contains some copper in solution and it takes on a greenish-blue tinge, the solution becomes more stable and better polishes are obtained. As the copper content increases, the current-voltage curve tends to be displaced toward the left and the necessary voltage decreases. Current density also tends to decrease. Some metaliographers prefer to keep the voltage just below point *D*. We have found some difficulty in keeping the anode free from bubbles, and polishing surfaces all over without points or dots appearing in relief. Surfaces without these dots in relief have been obtained if polishing was done at or near point *C′*, although a slightly longer time may be required.

After the cell shown has been used for several hours, a satisfactory polish of either brass or copper specimens is obtained if the voltage is held at 1 to 1.1 volts. Faster and better results can be obtained if the voltage is raised rapidly to that required for polishing, and then held constant. It is important to determine a current-voltage curve for any particular solution-concentration and any particular set-up of the electrodes. Agitation of the electrolyte for any reason while the cell is in use will generally cause the voltage to drop and vary considerably. The solution must be filtered occasionally to remove accumulations of metal particles which have not been dissolved in the solution or deposited on the cathode.

After a specimen has been polished it is important to remove it promptly just before the current is switched off. If the specimen is not rapidly removed or if the current is turned off first, a back electromotive force is set up which sometimes causes copper to plate out on the specimen. This copper can only be removed by repolishing in the solution for a short time. Any whitish film remaining after washing and drying may be removed by a dilute solution of ortho-phosphoric acid.



General Form of Current-Voltage Curve for Electrolytic Polishing of Copper or Brass in Aqueous Solutions of Ortho-Phosphoric Acid



Photomicrograph of Electrolytically Polished and Electrolytically Etched Specimen of Annealed 70-30 Brass; Magnified 75 Diameters

Preliminary Smoothing in HNO$_3$

It has been customary to prepare specimens for electrolytic polishing in the same manner as one would prepare a specimen for polishing on wet wheels. In general, the finer the surface the shorter will be the time necessary to produce a satisfactory sample for micro examination. Usually 10 to 15 min. is sufficient time for electrolytic polishing after a specimen has been worked down to a piece of 000 paper lubricated with graphite.

In an attempt to shorten the time, specimens were dipped in aqueous nitric acid solutions of various concentrations, for various times. Specimens were prepared for acid attack by slowly drawing them over a new and clean mill-smooth file to flatten and to remove previous cold work from the surface to be examined. Specimens which were swirled about in a 40% nitric acid solution for 30 to 45 sec. with the filed surface up and horizontal were found to be the most desirable. After 15 min. of electrolytic polishing the specimen is ready to be etched. The specimen whose structure is shown herewith was polished in this manner.

(Continued on page 98)

HARDENABILITY OF STEEL CALCULATED FROM CHEMICAL COMPOSITION

From Remarks Before ⊕ Tri-Chapter Meeting (Cincinnati)

By Marcus A. Grossmann
Director of Research
Carnegie-Illinois Steel Corp.

THE DIAGRAMS in the data sheet, page 81, adapted from the paper on the above subject before the February 1942 meeting of the American Institute of Mining and Metallurgical Engineers, illustrate one way in which hardenability may be calculated from chemical composition with a fair degree of precision. A definite steel is given as an example: Grain size, 7; carbon 0.50%, manganese 0.90%, silicon 0.10%, phosphorus 0.020%, sulphur 0.029%, nickel 0.28%, chromium 0.30%, molybdenum 0.05%, copper 0.05%.

In the proposed method, the steel is considered as having a base hardenability due to its carbon content alone, this base hardenability being the hardenability of a pure steel of the given carbon content, containing no other elements whatever, and of the given grain size. The base hardenability is read directly from the curves in the upper left diagram in the data sheet. The derivation of these curves from the available experimental data is shown in some detail in the A.I.M.E. paper mentioned above.

In the given steel the base hardenability is drawn from the curve in an obvious way at point *A* and is 0.24. This represents D_I, the "ideal diameter", that is, the size of bar that will harden at the center to a 50% martensitic structure when its surface is instantly cooled to 70° F. in the so-called ideal or perfect quench. This, of course, is a hypothetical quench, and a pure iron-carbon alloy is also a hypothetical material; nevertheless, the fiction of ideal diameter D_I has proven a useful basis for computation and comparison of the hardenability of various carbon and alloy steels.

This base hardenability is multiplied by a factor for each chemical element present. Thus, if manganese is added to the extent of 0.90% Mn, this much manganese introduces a multiplying factor of 4, noted as point *B* in the middle left diagram in the data sheet. This means that the diameter of bar which will just harden all the way through is four times as great as when no manganese is present. In our example a steel of grain size 7 containing 0.40% carbon and 0.90% manganese, and nothing else, would just harden all the way through in an ideal quench in a size 0.24 multiplied by 4, namely 0.96 or nearly 1 in. diameter. As remarked above, "harden all the way through" means that the microstructure at the center of the bar would be 50% martensitic.

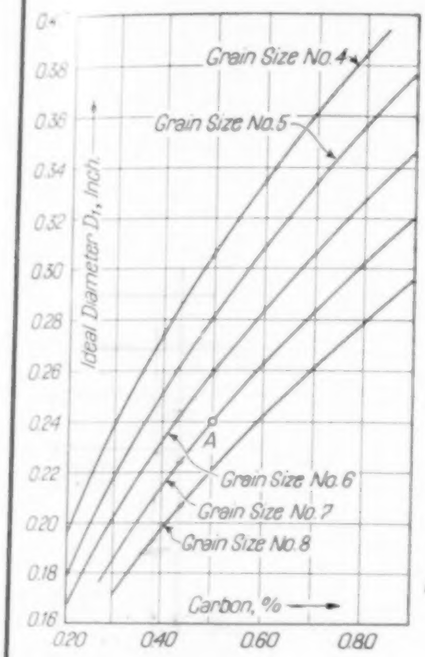
The further addition of 0.10% silicon introduces a multiplying factor of 1.10 (point *C* in the same diagram), so that a steel containing all three of these elements, in the amounts stated, would just harden all the way through

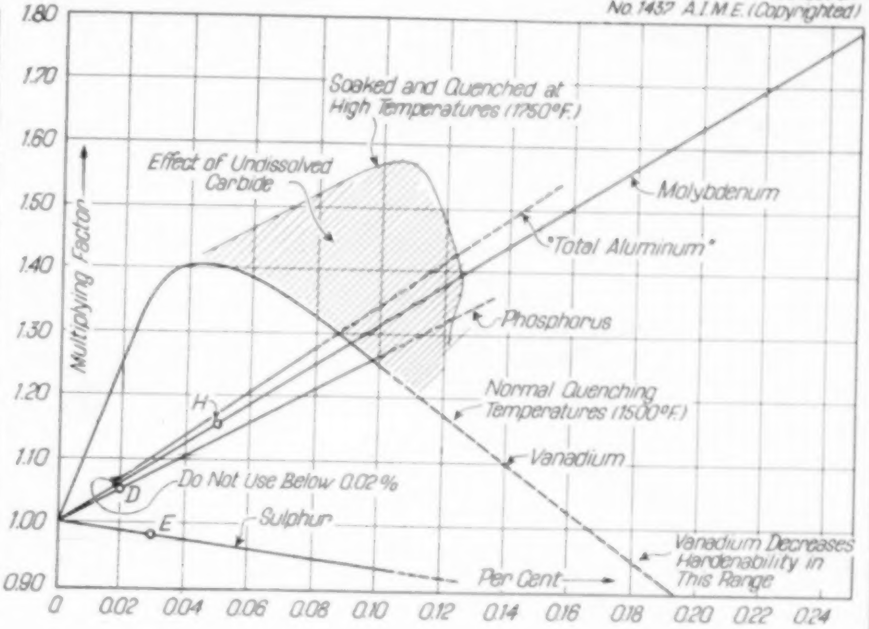
(Continued on page 124)

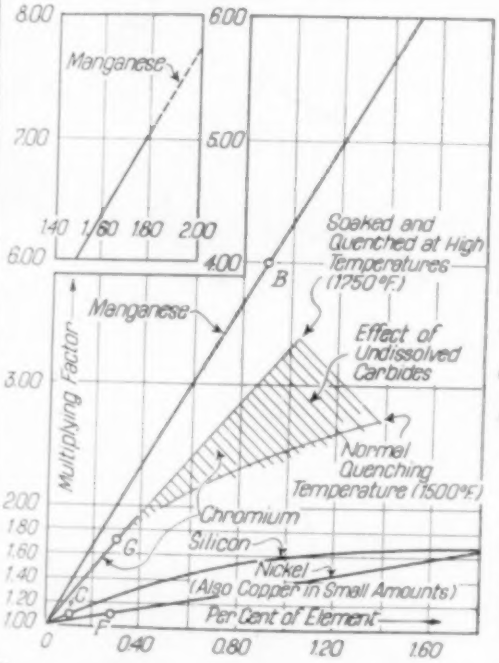
Hardenability Calculated From Composition

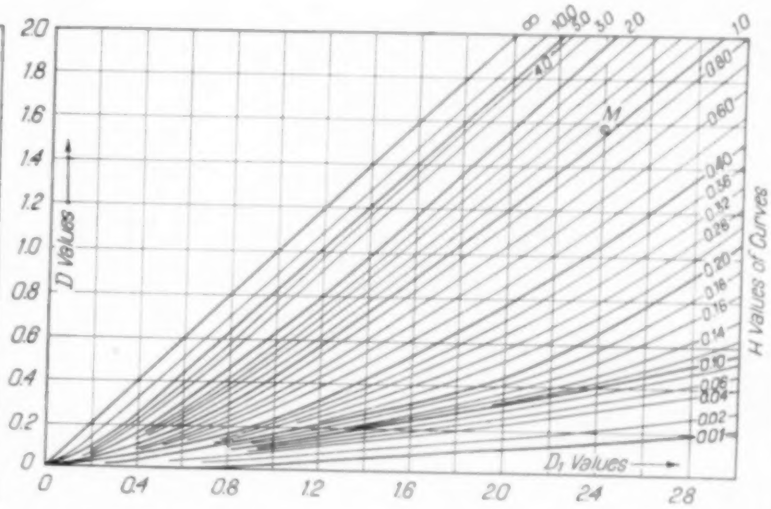
By *Marcus A. Grossmann*

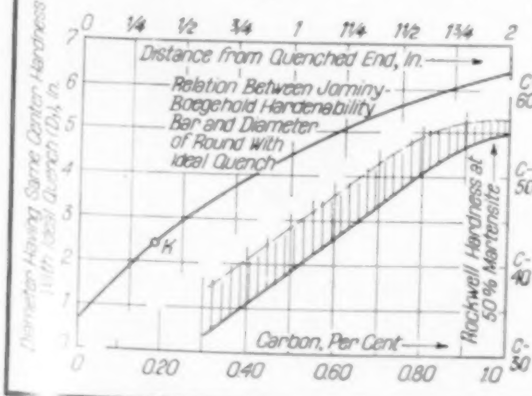
From Technical Publication No. 1437 A.I.M.E. (Copyrighted)











Example: To compute hardenability of a commercial steel of the analysis shown:

Ideal hardenability of given steel = D_I = $0.24 \times 4 \times 1.1 \times 1.05 \times 0.98 \times 1.1 \times 1.7 \times 1.16 \times 1.02 = 2.40$. Such figures for D_I will accurately compare one steel with another.

Jominy equivalent of the given steel at point *K*, that is, hardness of center of ideally quenched 2.40-in. bar, is the same as that found ⅜-in. from end of end-quenched specimen.

Actual hardness at center, taken from lowest curve, is about C-45 for 0.50 carbon, low alloy steel.

Item	Amount	Factor	Point
Grain size	7	0.24	*A*
Carbon content	0.50		
Manganese	0.90	4.00	*B*
Silicon	0.10	1.10	*C*
Phosphorus	0.020	1.05	*D*
Sulphur	0.029	0.98	*E*
Nickel	0.28	1.10	*F*
Chromium	0.30	1.70	*G*
Molybdenum	0.05	1.16	*H*
Copper	0.05	1.02	*

*Estimated on the line for nickel.

Quenching power H of commercial baths may be determined by methods shown in the data sheet, Metal Progress, Oct. 1941, page 520, or estimated from the table at right, below.

Example: Water quench, mildly agitated; H = 1.05; Steel D_I = 2.40. Actual critical diameter D (from point *M* above D_I = 2.40) is $1\frac{9}{16}$ in., size of bar of given steel that will harden in given quench to half martensitic structure at center; hardness C-45.

Circulation or Agitation	Value of H for		
	Oil	Water	Brine
None	0.25 to 0.30	0.9 to 1.0	2
Mild	0.30 to 0.35	1.0 to 1.1	2 to 2.2
Moderate	0.35 to 0.40	1.2 to 1.3	....
Good	0.4 to 0.5	1.4 to 1.5	....
Strong	0.5 to 0.8	1.6 to 2.0	....
Violent	0.8 to 1.1	4	5

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CRITICAL POINTS

By the Editor

more pig iron from 12 new blast furnaces

DISCUSSING with Rolland C. Allen, deputy chief of the Iron and Steel Branch, W.P.B. (and past president, American Institute of Mining and Metallurgical Engineers) the current large expansion of blast furnace capacity, and recalled that in the early days of O.P.M. he was insistent that shortages in scrap and pig iron would nullify any large expansion in openhearth steel capacity. Well-known events in recent history have proved his point, and caused the somewhat tardy adoption of his program to dig up all the scrap possible while building necessary blast furnaces to make pig iron when the scrap supply was drying up.... As of Jan. 1, 1941, our rated annual capacity for the production of pig iron was 56,522,370 net tons, over and beyond the charcoal iron and the ferro-alloy furnaces. A year later, Jan. 1, 1942, it was 59,211,850 net tons. So the average for 1941 was about 57¾ million tons capacity from which we actually produced 56 million tons of pig iron, an operating efficiency of 97%....Allen lists the new construction for 1942 as in the table below. Twelve more new furnaces with an annual capacity of 4,886,000 net tons will be blown in during the first half of 1943, and another million net tons capacity will be added by various enlargements, relinings, and the use of sinter instead of raw ore. This will give a capacity of almost 69 million tons by the close of next year. If the 97% efficiency of operations reached during 1941 is equaled, we can expect to get about 59 million tons of pig iron in 1942 and at least 64 million in 1943. Reference to Arthur G. McKee's article in Metal Progress for December 1941, page 918, shows that these figures almost exactly agree with his estimates of raw materials to be available.

Blast Furnace Program

		Annual Capacity	
		Company	Government
TURE	Operator and Completion Date	Financed	Financed
w	Tennessee Coal & Iron (April)	440,000	
w	Republic No. 1 (May)		280,000
built	Pittsburgh Coke & Iron (July)		144,000
w	Armco (August)	432,000	
built	Koppers United (August)	225,000	
w	Republic No. 2 (September)		390,000
w	Bethlehem No. 1 (October)		432,000
w	Bethlehem No. 2 (November)		432,000
w	Inland Steel Co. (November)	360,000	
w	Kaiser Iron & Steel Co. (December)		432,000
ved	U. S. Steel (December)	266,000	
ved	Columbia Steel (December)	300,000	
12 furnaces; total annual capacity		4,133,000 net tons	
Less listed capacity of old furnaces in 1942 estimates		952,650	
Net gain in 1942 from new furnaces		3,180,350	
Enlargements of existing furnaces		700,000	
Capacity as of Jan. 1, 1942		59,211,850	
Expected capacity, Jan. 1, 1943		63,092,200 net tons	

scrap steel still short

NOTED that Mr. McKee, in his article in Metal Progress, had in mind a serious shortage in scrap, and he estimated that these enlarged pig iron supplies would scarcely enable us to melt 80,640,000 tons of steel ingots in 1942 and only regain the 1941 production of 83,000,000 tons by 1943, yet hopeful that these figures are too pessimistic, for steel production during the first half of 1942 is already at the rate of 85 million tons. More iron is being reduced from ore in the openhearth, as recounted at the A.I.M.E. conference reported in Metal Progress for May, but the great drive for steel scrap is scraping the bottom of the bin. So would not be surprised at a lower openhearth production in the coming months, requiring all ASMembers to redouble efforts to make the available steel go further by producing less scrap in mill, forge and machine shop.

STOP the inefficiency you know about before you begin to worry about the inefficiency you hear about!

GLAD TO LEARN that the National Academy of Sciences has formulated a War Metallurgy Committee to advise the Army, Navy and other government agencies on special metallurgical problems, and to plan and supervise definite research projects for either war materials or armaments, and hopeful that such work may get under way without further delay, for in such matters as armor, guns and projectiles am convinced that it would be better for us to discover the new

wanted: better metals to fight hitler

alloys and treatments and surprise Hitler than vice versa. The Academy's existing Advisory Committee on Metals and Minerals has already responded to 113 requests from the Office of Production Management and the War Production Board in the past 18 months; these were principally on sources, substitutions and increased production of strategic materials. What is needed now is information on better ways to handle and use the available metals, and such problems ordinarily require research. Hence the new committee. Clyde Williams is chairman, Zay Jeffries is vice-chairman, and Louis Jordan is executive secretary. These three and 23 well-known metallurgists and research directors on the committee will certainly know how and where to study the problems, *if* the various government agencies realize that they have metallurgical problems needing study and ask for help. Do they know that they don't know?

☛ A serious bottleneck in heat treating capacity exists. Report *immediately* any idle furnaces to Bradley Stoughton, 4520 Social Security Bldg., Washington, D. C. ☚

INFORMATION of no aid or comfort to the enemy from Admiral H. L. Vickery, U. S. Maritime Commissioner: "Some of the bombs used early in May in the Battle of Coral Sea were transported to the Allied bases in ships whose keels were laid since the Jap attack on Pearl Harbor."

heat treater — mind that quench

TO THE OHIO Tri-Chapter Meeting at Cincinnati which considered NE steels, mostly, and which warranted this wire from Donald Nelson (no less): "The problem of making the fullest use of National Emergency steels is of vital importance to our war production program and I am confident that all of you will bend every effort to help the nation to make the most effective possible use of its critical metals in this emergency."....One other topic was considered, and that was toolsteels without vanadium. Howard Stagg, assistant manager of Halcomb Steel Co., believed that well-made steels of this sort would cause no more trouble than the change from 18-4-1 to the molybdenum high speeds. When the new steels are adequately marked and recognized, and quenched from the recommended lower temperatures, most users will not see any difference. Pleased also with Stagg's insistence that the quench is the most important and difficult part of heat treatment, yet oftenest honored by neglect. He asked, "Did you ever see a tool crack in the preheating, heating or tempering furnace?" Tool hardeners' troubles come from the volume changes when ductile austenite transforms to hard, brittle martensite, and to make sure that this occurs *during* the quench Stagg insists that the tool be cooled to where it can be handled bare handed. If your hardener has a date and must leave at five o'clock and the work is not yet that cool, let the watchman put it into the draw furnace rather than temper a warm and partly transformed piece.... Also recalled that Hal Chandler of Vanadium Corp. is fond of pointing out that expansion at the critical varies with the alloying elements, and that things like punches, chisels and armor piercing shot work best and have the least internal strain when made of an alloy and a heat thereof that has a minimum expansion during transformation. This property is easily susceptible of test.

can tin scrap make good steel?

UP BETIMES, and spent a reluctant hour on old tin cans, removing paper covers, refractory remnants of contents and bottoms — thereby acquiring a wound stripe on dexter arm — and so to wondering how the detinned steel sheet could be handled by the steel industry. Metal & Thermit Corp. has long operated detinning plants in a few industrial centers, thus recovering about 10% of the tin used for tinplate from the clean clippings from can manufacturers. Five years ago the same company started plants for treating tin cans, cleaned and shredded after collection, and now the Government is planning to finance other plants in populous centers where great numbers of cans can be readily salvaged. Possibly some of the solder can be sweated off, but the detinned product has contained about 0.25% of both tin and lead. Even though diluted with first class scrap and melted in an openhearth furnace, this doubtless will constitute a nuisance, both as metal to penetrate the hearth, and as fume to plug up the checkers.... Who has definite information on amounts that can be tolerated in steels of the various grades? Or should the bundled scrap — and there's perhaps a million tons a year of it in sight — preferably be fed to the cupola? Fred W. Willard of Nassau Smelting and Refining Co., New York City, is studying this subject for the National Academy of Sciences' Advisory Committee to W.P.B., and would welcome information about tolerances of tin in steel and foundry products and of experiences in melting large proportions of tin cans in the charge.

THE CHEMICO-PHYSICAL ROLE OF THE CUTTING FLUID

By Milton C. Shaw
Research Department
Cincinnati Milling Machine Co.
Cincinnati, Ohio

A CUTTING FLUID can be defined as any solid, liquid or gas applied to a cutting tool in order to control the quality of the surface produced or to facilitate the removal of metal. Less power will be required, the tool will be kept cooler, tool life will be increased, and many other advantages will be realized by the use of the proper cutting fluid.

Not much has been written concerning the fundamental nature of its action. The general belief has been that cutting fluids are helpful because of their lubricating ability. It should at once be evident, however, that the conditions obtaining during the removal of metal are not conducive to the establishment and maintenance of a hydrodynamic film. The extremely high pressures and local temperatures reached in metal cutting, together with the geometry of the metal cutting process, preclude any chance for a hydrodynamic film. Hans Ernst has shown in his contribution on "Physics of Metal Cutting" in the ⊕ book "Machining of Metals" that there is generally no gap between the chip and the work extending beyond the tool point. Instead, the chip closely follows the surface of the tool from its very point, and contact between chip and tool is in the form of a great number of small bridges which produce a labyrinth of capillaries. Large capillary forces are therefore available to draw the cutting fluid into the zone of action. Consequently the action is not akin to hydrodynamic lubrication but belongs to that large class of problems unfortunately called problems of boundary lubrication. (The word *lubrication* naturally conveys the idea of a hydrodynamic film, but no such film exists in *boundary lubrication*.)

A considerable amount of work has been done during the past decade in the field of boundary lubrication, and Otto Beeck has written an excellent review of the subject in *Journal of Applied Physics*, July 1941 (abstracted in Metal Progress for November 1941, page 808). The field of boundary lubrication is generally understood to include all problems involving the reduction of the resistance to sliding, experienced by rubbing surfaces which make direct contact, and it can be divided into four main types corresponding to the four possible combinations of high and low pressures and surface temperatures.

Bowden and Tabor found from conductivity experiments that all of the deformed surface between two sliding bodies had been in contact, and therefore they favor a plastic theory of contact over an elastic theory. (See *Proceedings* of the Royal Society for 1938, page 391.) The pressure developed between two sliding surfaces is a constant for any given material and is equal to the hardness of the metal. The pressure developed in metal cutting will be greater than that developed in the sliding of the same materials because the cut material will be almost completely work hardened, and the apparent hardness will be further increased when the cutting speed is a significant fraction of the velocity of propagation of stress in the material.

In the light of recent investigations, it appears that the chief requisite for an effective fluid for the two low temperature types of boundary lubrication at high and low pressure, is that the compound be highly polar and capable of being strongly bonded to the surfaces. (A different mechanism is necessary for the two high temperature types of boundary lubrication, since a physically bonded surface layer would be incapable of withstanding the very high surface temperatures involved.) As a result of experiments conducted in the Research Laboratory of the Cincinnati Milling Machine Co., it has been shown that, under the high pressure and surface temperature prevailing at the chip-tool interface, certain fluids will react chemically with the metal being cut, forming reaction products between the sliding surfaces. These reaction products, usually organo-metallic compounds or metal salts, are generally solids, and are thus capable of withstanding much higher temperatures than liquids. Metal compounds usually have much lower shear strengths than the corresponding metals, and hence the cutting force will be considerably lowered if metal-to-metal contact is reduced by the formation of such a metallic compound between the sliding surfaces.

In addition to temperature and pressure, a third variable should be considered in the classification of boundary lubricants. This third quantity is the amount of fresh or nascent metal surface produced, for it will have an important bearing upon the chemical reactions just mentioned. In ordinary "sliding boundary lubrication" the amount of fresh metal surface formed will be small, since the actual area of contact is small due to the relatively low loads involved. From a practical point of view there is always some metal-to-metal contact and subsequent welding, followed by rupture of the bridges thus established. BEARE and BOWDEN reported in the *Transactions* of the Royal Society for 1935 (page 329) that abrasion was found even when the best boundary "lubricants" were used.* The quantity of the highly reactive surface material will increase with the applied load, and will be a maximum in the case of metal cutting, since all of the cut surface is nascent at the instant it is ruptured.

It is thus clear that cutting fluid action occupies a small portion of the huge field of boundary lubrication. Extreme pressures up to the maximum hardness of the metal, temperatures up to the melting point of the metal, and a maximum of newly formed and highly reactive chip surface are involved. Thus, it appears that the only type of mechanism feasible in cutting fluid action is one in which the fluid reacts chemically with the newly formed metal surface to form a solid chemical product. The writer has called this mechanism "chemico-physical" because the action is initiated by a chemical reaction between fluid and nascent surface, and is followed by a decrease in frictional resistance, due to the relatively lower shear strengths of the metal compound than of the work material.

In the course of a fundamental investigation of cutting fluid action we studied the effect of mixtures of benzene and n. decanol when cutting aluminum at very low cutting speeds. An interesting phenomenon was observed which is readily explained in terms of the chemico-physical theory of cutting fluid action, but which would be very difficult to explain on any other basis. For this reason a short description of this phenomenon may serve to illustrate the working of the foregoing theory.

The manner in which the tests were made is shown diagrammatically in Fig. 1. A chip was

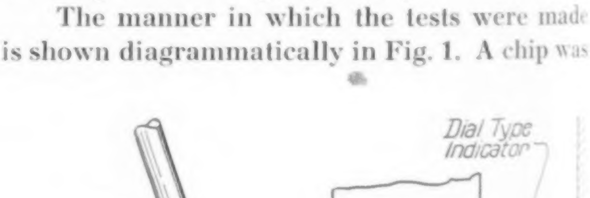

Fig. 1 — Experimental Set-Up for Estimating Force Required to Remove Chips From an Aluminum Bar at Slow Speed, by Measuring Deflection of Tool Holder

cut from an aluminum work block using a high speed steel cutting tool. Tests were made at the very low cutting speed of 5.50 in. per min., and the depth of metal removed was 0.005 in. The space between tool and work piece was kept filled with the liquid by a dropper. The force necessary to remove a chip was measured by a previously calibrated dial type indicator showing the deflection of the tool holder in units of 0.0001 in.

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*A review of the work of BOWDEN and his associates on sliding, friction and vibration was printed in METAL PROGRESS for April 1940, page 435.

The work piece was a 3×1¼-in. bar of commercially pure aluminum. The n. decanol and o. xylene used in this investigation were fractionated before using in a distillation apparatus with an efficiency of about nine theoretical plates. The benzene used was C.P. grade and free of thiophene.

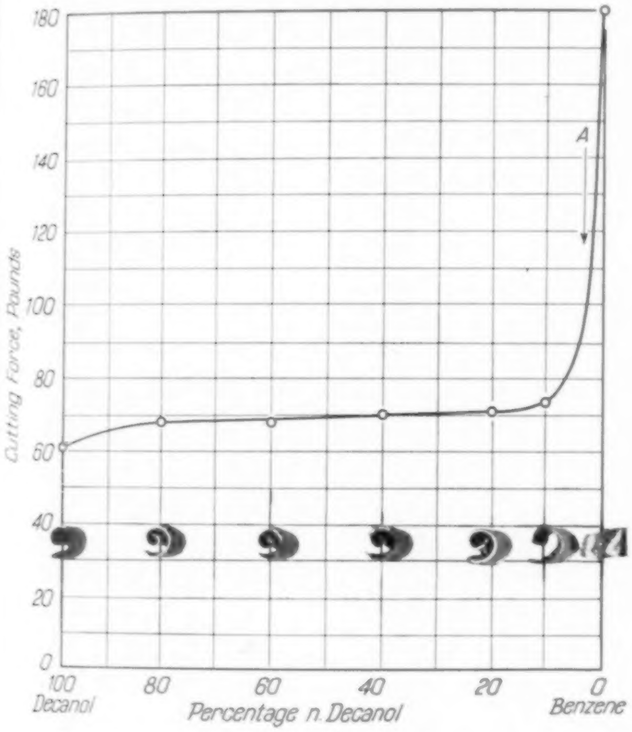


Fig. 2 — Variation in Cutting Force and Appearance of Chip When Cutting Aluminum With Mixtures of Alcohol and n. Decanol

Several mixtures of benzene and n. decanol were prepared and tested as described above, and the variation in the cutting force using mixtures ranging from pure n. decanol to pure benzene is plotted in Fig. 2. The cutting force is the component of the resultant force on the tool parallel to the direction of cutting. The complete chip obtained in a 3-in. cut is shown below the concentration of each mixture used.

In previous tests it has been found that chip length and chip thickness vary with the cutting fluid. An effective liquid causes a low coefficient of friction and produces a long thin chip and a good finish, while a less effective fluid gives a shorter, thicker chip and a poor finish. The gradual change in chip appearance with the change in concentration of the active ingredient is clearly illustrated by the chips in Fig. 2.

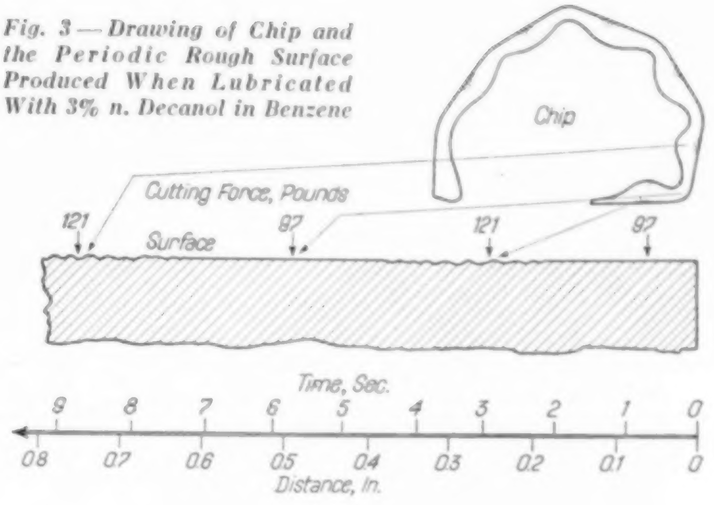


Fig. 3 — Drawing of Chip and the Periodic Rough Surface Produced When Lubricated With 3% n. Decanol in Benzene

Below a concentration of 7% by volume of n. decanol in benzene, the chip produced was not at all uniform. Its thickness varied periodically along its length and, on closer examination, the finished surface was found to be alternately rough and smooth with a period corresponding to the variation in thickness of the chip. The cutting force likewise fluctuated periodically throughout the progress of a cut. This phenomenon first appeared at a concentration of 7% n. decanol in benzene, was most pronounced at 3% and finally disappeared at a concentration of 1%.

An enlarged drawing of one of the chips and of the corresponding surface produced with a concentration of 3% n. decanol in benzene is shown in Fig. 3. Maxima and minima in the cutting force are indicated and related to the periodic rough spots on the surface. A time scale is included and it can be seen that the period of fluctuation is about 6 sec. Photomicrographs of the rough and smooth portions of the surface are shown in Fig. 4 and 5.

Tests were also made in which o. xylene was used in place of benzene and a similar fluctuation of cutting force was observed in the same range of concentrations.

The periodic variation of cutting force, chip thickness and surface smoothness described above can be explained readily in terms of the chemico-physical theory of cutting fluid action.

It is believed that these phenomena arise from a critical relationship existing between the surface temperature, the pressure, concentration of the active ingredient in the mixture and the amount of reaction product. It is reasonable to expect that a certain minimum quantity of reaction product of low shear strength will be required to produce an appreciable reduction in the coefficient of friction between chip and tool — and consequently a noticeable improvement in finish and a decrease in cutting force. At a critical dilution of the active ingredient, the rate of production of the reaction product falls off rapidly; consequently, the cutting force rises sharply as at Point *A* in Fig. 2, where the cutting force increases suddenly with a slight decrease in the concentration of n. decanol. When a slight change in concentration causes such a large change in cutting force, one may expect to find a state of instability.

At the beginning of a cut, the surface temperature and the force increase gradually to a high value. In the critical region of 3% by volume of n. decanol in benzene, the concentration of active ingredient is just sufficient, at this high surface temperature and force, to produce enough reaction product for effective cutting fluid action, thus decreasing the frictional resistance and the cutting force. At this reduced cutting force, the surface temperature and area of contact are decreased, and thus the quantity of the chemical product formed is insufficient for effective cutting fluid action; therefore, the force and surface temperature once more increase. This cycle will be repeated periodically.

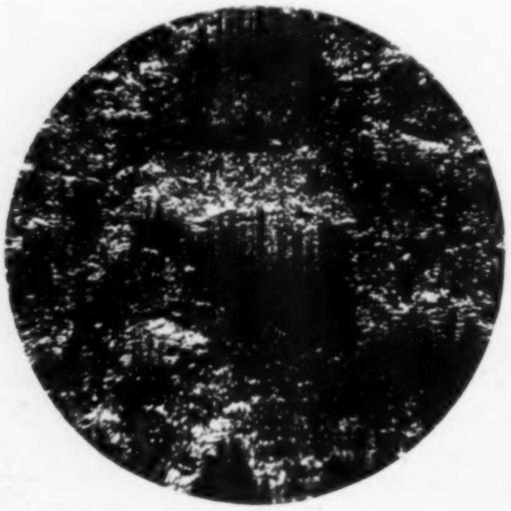
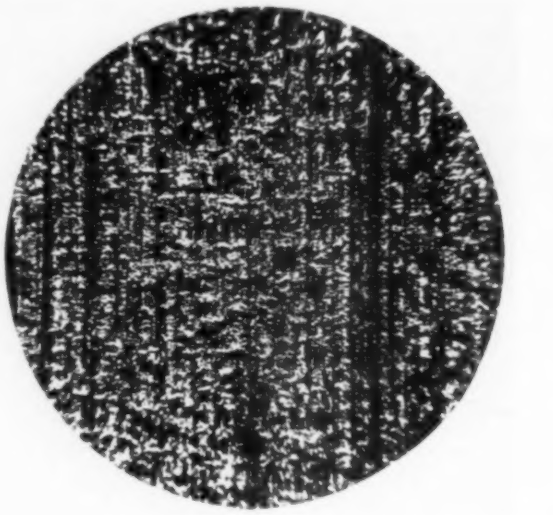


Fig. 4 (above) and 5 (below) — Micrographs Respectively of Rough and Smooth Portions of Aluminum Surface, Magnified 25 Diameters

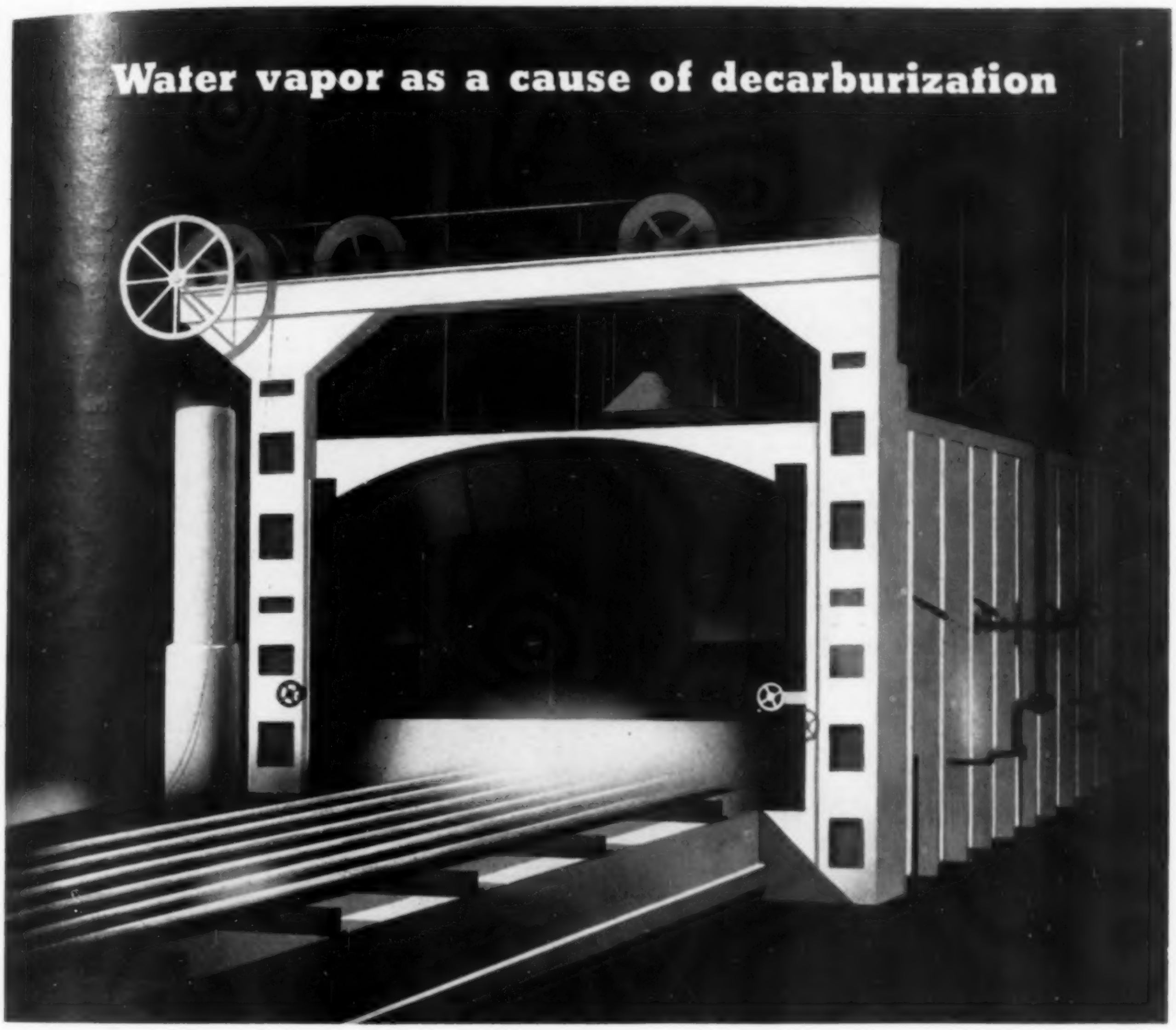


The fact that the period of the fluctuations described above is as long as 6 sec., and corresponds in this experiment to a tool travel of about ½ in., eliminates any possibility that this phenomenon is due to chatter or to any other periodic variation of the mechanical system.

A few tests were made with o. xylene as the solvent in order to ascertain whether the rate of evaporation of the solvent would have any effect upon the observed fluctuation. Like benzene, o. xylene is a poor cutting fluid, but it is much less volatile than benzene. The fact that the same period of fluctuation was observed when o. xylene was used in place of benzene shows that this effect is independent of the volatility of the solvent.

Although the foregoing phenomenon is only one of many significant results observed in our fundamental investigations of cutting fluid action, it is worthy of special mention because it is unique and can be explained in terms of the chemico-physical theory herein described; thus it illustrates well the workings of this theory. While this example may have no immediate application in the commercial cutting of metals, it is not presented from this standpoint, but rather as another significant finding in the study of metal cutting fundamentals — a study which is being pursued on many fronts, and which, as in the past, will continue to improve basically the processes of commercial metal cutting.

Finally, the writer wishes to acknowledge the cooperation of staff members of the Applied Science Research Laboratory of the University of Cincinnati and of the Research Laboratory of the Cincinnati Milling Machine Co.



Water vapor as a cause of decarburization

Information supplied by "Metal Progress"

Experience shows that the decarburization of steel in special atmosphere heat treating furnaces can often be traced to water vapor formed in the furnace.

Given knowledge of the conditions that cause it, and sure means of detecting its presence, elimination of water vapor can be accomplished by taking appropriate steps.

The formation of water vapor is due to the effect of high temperature on the composition of the furnace atmosphere. Compositions that apparently have proper constituent ratios when they leave the preparation unit may, and almost always do, change at operating temperatures.

The most important change is that known as the "water gas" reaction. If there are CO_2 and H_2 in the atmosphere gas, the following reaction will take place:

$$CO_2 + H_2 = CO + H_2O$$

Under such conditions, a "bone dry" atmosphere can readily produce H_2O in the furnace, and thereby cause decarburization.

Manufacturers of special atmosphere units are giving increasing attention to the best methods of avoiding the presence of CO_2. They will be glad to suggest the best method for individual cases.

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PERSONALS

George I. Calvert is on leave of absence from his position as metallurgist, D. & B. Division, Emsco Derrick & Equipment Co., called to active duty with the Ordnance Department as first lieutenant, assigned to the Production Service Division, St. Louis Ordnance District.

L. C. Conradi, formerly in charge of the technical and research activities of the International Business Machines Corp., has become affiliated with the Standard Steel Spring Co. as ordnance chief metallurgist.

J. H. Dodge, chairman of the Toledo Group, has been appointed district manager of the Toledo branch of the Latrobe Electric Steel Co.

W. J. Reagan has severed his connection with Edgewater Steel Co. at Oakmont, Pa., and has joined the metallurgical engineering staff of the Copperweld Steel Co. at Warren, Ohio.

Reginald S. Dean, chief of the metallurgical division, Bureau of Mines, has been appointed assistant director of the Bureau.

Karl F. Schauwecker, vice-chairman of the Calumet Chapter, has been transferred by Carnegie-Illinois Steel Corp. to Milwaukee as metallurgical contact representative in that district.

R. Zirkind, formerly naval inspector at Pontiac, Mich., is now inspector of optical material for the Chicago area for the U. S. Navy.

Richard A. Page, formerly with Reed-Prentice Corp., Worcester, Mass., is now with the Army Air Force, Materiel Division, Inspection Section, stationed at American Bosch Magneto Corp., Springfield, Mass.

R. H. Soll has been appointed general manager of the White Heat Treating Co., Huntington Park, Calif.

O. J. Wick, formerly mill superintendent, has been appointed general superintendent for Pacific Mining Co., Morton, Wash.

Richard J. Tatousek is now with American Locomotive Co., Chicago Heights, Ill., as assistant metallurgist of the Railway Steel and Spring Division.

Robert E. Hartsock has been transferred by J. I. Case Co. to the Gun Mount Division with responsibility for engineering on anti-aircraft guns in five plants.

Hans Bohuslav, formerly vice-president in charge of engineering for Enterprise Engineering Co. of San Francisco, has joined the Sterling Engine Co. of Buffalo, also as vice-president in charge of engineering.

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PERSONALS

G. W. Strahan ⊕ is leaving the International Nickel Co., where he was in the nickel sales department, to serve as a first lieutenant in the Air Forces of the U. S. Army.

Promoted: **Wayne L. Cockrell** ⊕, from captain to major, serving in the Detroit Ordnance District.

Robert G. Maurer ⊕ has accepted a position with Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa., as manufacturing engineer.

Cyril Stanley Smith ⊕, research metallurgist, American Brass Co., Waterbury, Conn., is now serving as research supervisor, War Metallurgy Committee, National Research Council, Washington, D. C.

Orlo E. Brown ⊕, assistant professor of chemical engineering in charge of metallurgy at West Virginia University, is now connected with the Vega Aircraft Corp. of Burbank, Calif., as a production processing engineer.

E. J. Egan, Jr. ⊕ has resigned his position as a salesman for the Cincinnati district office, Federated Metals Division of American Smelting and Refining Co., to become metallurgist for Ridgewood Steel Co., Cincinnati.

Ronald Vingoe ⊕ is now connected with the War Department, Signal Corps, Wright Field, Dayton, Ohio, as chemical engineer.

Robert J. King ⊕ is employed as a metallurgist by the Dow Chemical Co., Midland, Mich.

C. H. Fitzwilson, Jr. ⊕, formerly in the sheet and strip metallurgical bureau, Carnegie-Illinois Steel Corp., is now a contact metallurgist for the tin plate bureau of the Chicago metallurgical department of Carnegie-Illinois.

Transferred by Bridgeport Brass Co.: **R. J. Gardner** ⊕, from Bridgeport, Conn. to Indianapolis, Ind., as assistant plant engineer for the Indianapolis Ordnance Project.

C. F. Quest ⊕ received his Ph.D. in Metallurgy at University of Minnesota in March, and is now employed as metallurgist in charge of the heat treating division of Chattanooga Stamping and Enameling Co., Chattanooga, Tenn.

L. W. Papendick ⊕, formerly assistant chief metallurgist at Northwestern Steel & Wire Co., is now in the research department of Lindberg Engineering Co., Chicago.

Joseph G. Christ ⊕, formerly research engineer at Battelle Memorial Institute, is now materials engineer at the East Pittsburgh plant of Westinghouse Electric & Mfg. Co.

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PERSONALS

Promoted: **E. E. Sanborn** ⊕, to manager of toolsteel sales in Allegheny Ludlum Steel Corp.'s Cleveland territory.

Maurice C. Fetzer ⊕, formerly assistant professor of metallurgy at Pennsylvania State College, has joined Carpenter Steel Co. as a research metallurgist.

Albert E. White, past president and founder member ⊕, director of engineering research, University of Michigan, has been nominated for a manager by the American Society of Mechanical Engineers.

Walter L. Snyder ⊕ has changed his connection from the Blaw-Knox Co. laboratories to the Continental Roll and Steel Foundry Co., Coraopolis, Pa.

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Joseph I. Wexlin ⊕, formerly district manager for Bausch & Lomb Optical Co. in Philadelphia, has reported for duty with the Army Ordnance Department, assigned as officer in charge of the Bethlehem sub-office of the Philadelphia Ordnance District.

Alfred Sonntag ⊕, formerly chief engineer and sales manager of the Riehle Testing Machine Division of American Machine and Metals, has joined the staff of the testing machine department of the Baldwin-Southwark Division of the Baldwin Locomotive Works, Philadelphia.

Harry Czyzewski ⊕ is at present in the research laboratory of Caterpillar Tractor Co.

Morton C. Smith ⊕ has returned to the United States after three years in the metallurgy department of the University of Alaska, to accept a position as assistant professor of metallurgy at the Montana School of Mines in Butte, Mont.

Elected to the Canton City Council: **Clifford W. Gehrum** ⊕, metallurgist at Republic Steel Corp.

Harris P. Moyer ⊕ is now chief metallurgist for the American Propeller Corp., Toledo, Ohio.

Appointed to Industry Advisory Committees, Division of Industry Operations, War Production Board: **W. J. Priestley** ⊕, vice-president of Electro Metallurgical Co., New York, to the Ferrochromium Producers Industry Committee; **H. E. Passmore** ⊕ engineer, National Tube Co., Pittsburgh, to the High Pressure Steel Gas Cylinder Manufacturers Industry Committee.

Burton H. Gedge ⊕, assistant to vice-president in charge of operations of American Steel & Wire Co., has been promoted to new duties specializing in production activities of the vice-president's office. **Harry L. Jenter** ⊕ has also been made assistant to vice-president.

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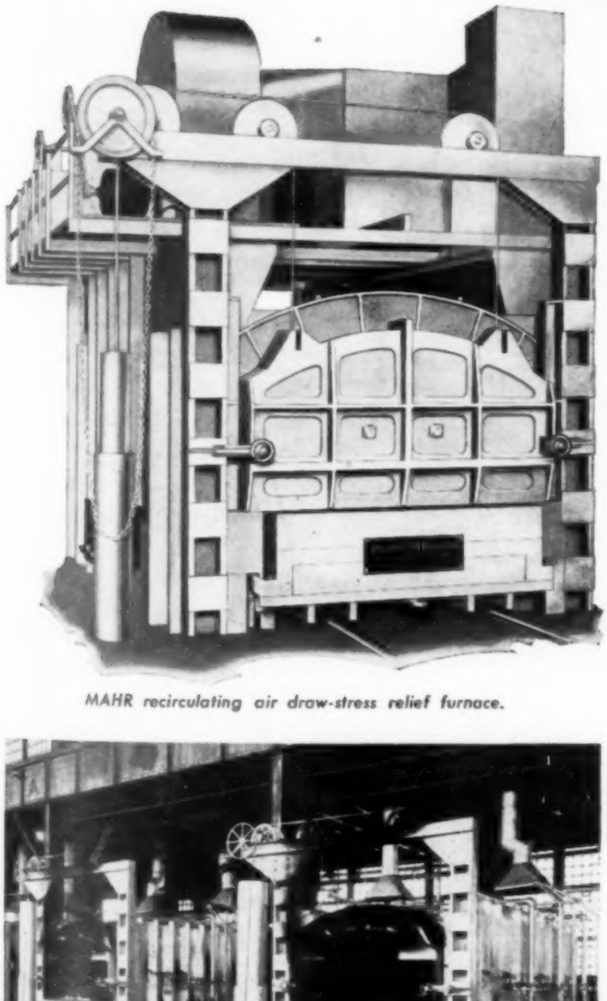

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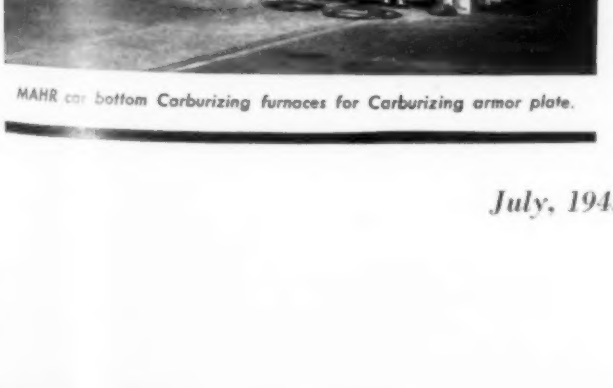

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PERSONALS

E. G. Jennings ⊕, formerly metallurgist, Canadian Bronze Co., Montreal, is now metallurgist, McKay Smelters, Ltd., Ottawa, Ont.

Lieut. N. A. Birch ⊕ has been ordered for active duty at Watertown Arsenal, associated with the heat treat division.

Paul Keller ⊕, formerly of the Cleveland sales district, has been appointed to manage the sales of tool, stainless, and special steels for the Copperweld Steel Co., Warren, Ohio.

R. S. Ahlbrandt ⊕, Pittsburgh district sales manager for Allegheny Ludlum Steel Corp., has been granted a leave of absence to accept a lieutenant's commission in the United States Navy.

H. Fiosne ⊕ is now metallurgist at International Harvester Co., Bettendorf Works, Bettendorf, Iowa.

James Allison ⊕, formerly of Billings & Spencer Co., served three months in the Connecticut State Office of the War Production Board and is now chief metallurgist of the Star Drilling Machine Co. of Akron, Ohio.

Edward Schmotzer ⊕ is now connected with the National Advistory Committee for Aeronautics, Engine Research Laboratory, Cleveland, as assistant electrical engineer.

Personnel changes on the staff of American Steel & Wire Co.: In Cleveland—**John S. Richards** ⊕ has been appointed director of research and is succeeded as manager of the metallurgical department by **James R. Thompson** ⊕. **Flint C. Elder** ⊕, formerly director of research, is now research engineer on special assignments from the vice-president. **Lawrence H. Dunham** ⊕ has been made assistant manager of the metallurgical department. **Oscar T. Marzke** ⊕, formerly works metallurgist at North Works in Worcester, has been named works metallurgist, Waukegan, Ill. **Wade B. Houk** ⊕ has been appointed works metallurgist at Worcester. **Charles E. Williams** ⊕, formerly assistant general foreman of the open-hearth department, Donora Steel Works, Donora, Pa., has been transferred to the Cleveland headquarters and appointed to the vice-president's office.

Charles M. Craighead ⊕ has been named a research metallurgist on the staff of Battelle Memorial Institute, Columbus, Ohio.

H. T. Herbst ⊕ has changed from district engineer to division engineer of Linde Air Products Co. in Los Angeles.

Melvin J. Brown ⊕ is a metallurgical observer, Homestead Works, Carnegie-Illinois Steel Corp., Pittsburgh.

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PERSONALS

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James Allison ⊕, formerly of Billings & Spencer Co., served three months in the Connecticut State Office of the War Production Board and is now chief metallurgist of the Star Drilling Machine Co. of Akron, Ohio.

Edward Schmotzer ⊕ is now connected with the National Advisory Committee for Aeronautics, Engine Research Laboratory, Cleveland, as assistant electrical engineer.

Personnel changes on the staff of American Steel & Wire Co.: In Cleveland — **John S. Richards** ⊕ has been appointed director of research and is succeeded as manager of the metallurgical department by **James R. Thompson** ⊕. **Flint C. Elder** ⊕, formerly director of research, is now research engineer on special assignments from the vice-president. **Lawrence H. Dunham** ⊕ has been made assistant manager of the metallurgical department. **Oscar T. Marzke** ⊕, formerly works metallurgist at North Works in Worcester, has been named works metallurgist, Waukegan, Ill. **Wade B. Houk** ⊕ has been appointed works metallurgist at Worcester. **Charles E. Williams** ⊕, formerly assistant general foreman of the open-hearth department, Donora Steel Works, Donora, Pa., has been transferred to the Cleveland headquarters and appointed to the vice-president's office.

Charles M. Craighead ⊕ has been named a research metallurgist on the staff of Battelle Memorial Institute, Columbus, Ohio.

H. T. Herbst ⊕ has changed from district engineer to division engineer of Linde Air Products Co. in Los Angeles.

Melvin J. Brown ⊕ is a metallurgical observer, Homestead Works, Carnegie-Illinois Steel Corp., Pittsburgh.

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This space is a contribution to America's all-out war program by

METAL PROGRESS

POLISHING

(Continued from page 79)

The unetched surface of the metal cannot be focused sharply and is not useful in determining the nature or presence of inclusions, since the acid attack and the electrolytic polishing destroys the identity of the inclusions and produces some pits which might be mistaken for inclusions or voids.

Alternative Equipment — Specimens may be etched in the customary manner by swabbing for a few seconds in a freshly made solution containing 9 parts of 50% ammonium hydroxide and 1 part of 9% hydrogen peroxide. Specimens can also be electrolytically etched by a procedure described in detail by G. C. Williams and G. Rieger in *The Metal Industry* for May 24, 1940, page 461, in which the specimen is made the anode with an optimum current density of about 2 amperes per sq.in. (31 amp. per sq. decimeter) for several seconds in an electrolyte as follows: 10 ml. of 0.10M ammonium acetate, 30 ml. of 0.14M ammonium hydroxide, 30 ml. of 0.50M sodium thiosulphate, 30 ml. of distilled water.

Good results are obtained in a cell similar to that described for polishing, except with a stainless steel anode and cathode. It is important to keep the anode clean so that good contact can be maintained with the specimen. The surface to be etched should be vertical and parallel to the cathode. This cell also gives best results after it has been used several times. The optimum size for the steel cathode is 15 sq.in. and the best anode size is 1.5 sq.in. The cathode should be placed about ¾ in. from the anode platform. Good etching results have been obtained on specimens about 1 sq.in. in surface area, using a potential of about 3½ volts and a current density of about 0.1 amp. per sq.in. (about 1.5 amp. per sq. decimeter) for about 10 sec.

All methods of electrolytic polishing and etching require some individual observations to determine the most suitable operating conditions for the particular cell being used. The methods described in this article can be satisfactorily applied to copper and brass specimens in which only one phase (the alpha phase) is present. If more than one phase is present, only the alpha phase will usually be polished, while the beta phase will appear etched or pitted out. However, there is no doubt that electrolytic polishing, and the method of chemical attack in nitric acid to eliminate the smoothing on paper prior to electrolytic polishing, makes the preparation of copper or brass specimens easier and faster.

This space was reserved to tell some of the most sensational stories of the prominent place held by our Phytanium-Blended **PENTRATE**, *the patented black finish for steel, on defense contracts throughout the country. These stories might have revealed names, places, or items—all of which are military secrets. So we censored this ad of our own free will in the interest of national defense.*

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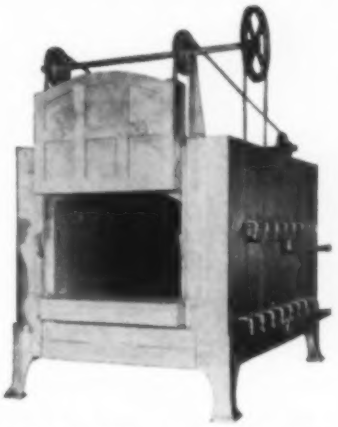

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by H. J. French

In Charge of Alloy Steel and Iron Development
International Nickel Co.

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Some Questions and Answers on
New National Emergency Analyses

National Emergency (NE) Steels are a series of new alloy analyses, developed, at WPB's request, to supplant standard steels of rich strategic alloy content. These new analyses are recommended by WPB as alternates for present nickel, chromium and chrome nickel constructional alloy steels.

What is the Purpose of NE Steels? Extensive substitution of NE grades for present standard analyses will "stretch" our supply of critical nickel and chromium. Greater use of manganese and moly will help speed alloy steel production and deliveries. WPB states that "NE steels and certain others containing less, or no strategic elements will soon be only steels available". You are urged to change as quickly as possible, to be prepared when present standard analyses are cut off.

What are NE Analyses? A list of present standard alloy "specs" and recommended NE alternates, showing chemical compositions, may be obtained by mailing the coupon below to Peter A. Frasse and Co., Inc.

How About Physical Properties? Extensive tests are now being made on NE grades, results of which will be furnished on request. Conclusive data will be published as soon as sufficient tests are accumulated.

When Will They Be Available? Test heats have already been melted by most alloy mills. Frasse will stock NE grades as fast as mill rolling schedules permit. Details will be furnished shortly. *Peter A. Frasse and Co., Inc., 17 Grand Street, N.Y.C. (Walker 5-2200) • 3911 Wissahickon Ave., Philadelphia, (Radcliff 7100 - Park 5541) • 50 Exchange Street, Buffalo (Washington 2000) • Jersey City, Hartford, Rochester, Syracuse, Baltimore.*

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ALUMINUM

(Continued from page 76)

delivery on steam power equipment and the need for a quick source of power, other arrangements had to be made.

At this plant, we were being supplied with natural gas at a very low price, so we are installing 60 Cooper-Bessemer gas engines each driving a 750-kw. generator, and 18 larger Nordberg engines each direct coupled to a 2250-kw. generator. These are low voltage, direct current generators and the power is transmitted directly to the production line without transformer or converter losses. The conventional procedure is to generate alternating current at high enough voltage for economic transmission and then convert at the delivery end to direct current for the cells by means of mercury arc rectifiers. The elimination of this equipment makes the price of gas-engine power compare favorably with that from other sources. With cheap natural gas we believe it will be a very economical installation, in spite of the large number of units required.

Finally there is one thought I would like to leave with you. Aside from our operating expenditures, the Aluminum Co. of America will have spent for construction from January 1, 1940, to the middle of 1943, just about $600,000,000. We have not yet been seriously behind schedule and have been ahead in some cases. No organization the size of ours could have handled this work without the cooperation of everyone connected with it. Engineering, purchasing, construction, operating, coordinating, and priority divisions all feel that it is their job. Everyone from the blueprint boy up is anxious to see the schedules kept and takes personal pride in beating them. This is the only way it could have been done.

HE FOOTSTEPS OF GENERAL ALLOYS MARK THE PATH OF AN INDUSTRY

ANDA writers have wallowed in ink, spread es of paper, to awake in labor a realization ation's need. All of these to us have less than the two simple writings—the Epitaph right, and Mrs. Brooks' letter to Defense rikers, reproduced below. Our strike is over men are back at work. In due course the or Board will release a statement, at which will comment fully and frankly.

derstand Disney has a new character, Super who ties cats together by the tails, juggles cheeses, etc. This would be Disney's great- to America. Disney has given release from choice—"Am I man or mouse?" Millions mice will greet their prototype with grati-

DE GERARD introduced a sparkling blond ngton's Mayflower as the inventor of the 11 Questioned, the lady elucidated, "There are called down here, who up to now would not h other with a 10-foot pole, that we had to some relief."

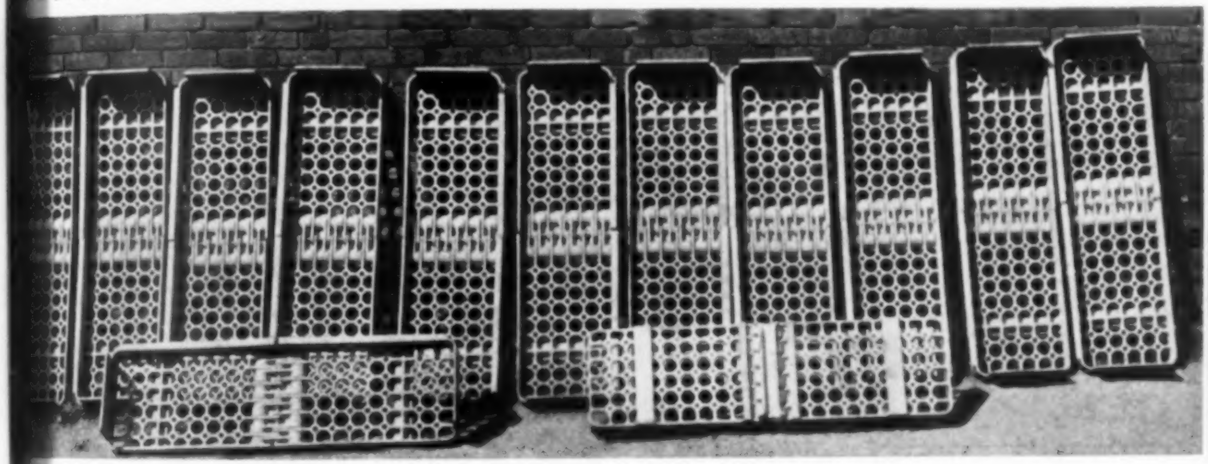
GE as it may seem, we encountered an in- y incompetent individual in a high gov- job. We had known him in his moronic days. "How did you get into the govern- we asked him. "Well," he replied, "you I always shot my arrows into the air and they rth I knew not where, but I lost too damn rows. Now I have got plenty of arrows and, what swell targets." We suspect ourselves get.

ious and quite realistic way to save nickel omium in heat resisting alloys is by engi- one pound of alloy to do the work of two. been accomplished in many General Alloys introduced by sound engineering judgment r urgency developed. One of these designs nged tray, a row of which appear below.

EPITAPH 1942

For lack of ships and planes and tanks
We lie here where we fought, in serried ranks,
Because, too little and too late,
The shift made six instead of eight.

THE most inspirational American Utterance on our Nation's need which has come to our attention at General Alloys is the above, credited to President Hotchkiss of Rensselaer Polytechnic Institute, whose war contributions are manifold.



June 7. 1942

the Striking Workers
t General Alloys.

women whose sons must
fight this war, where cruelty and
speed outdo each other, read
with shame and anger of
your desertion in your country's
hour of need. Be ware lest
your own mothers curse you,
and your own children cry
out in terror at what you
can now prevent

Selfish and blind you must
be not to see that such work
as yours must continue and
increase many times over, lest
the nation die. If you cannot
see, we can.

Must we leave our kitchens and
our homes and do your jobs
for you; or will you fall to,
and fight with all your skill
and strength to help the boys?

We mothers need your answer
and soon
Mrs. Florence C. Brooks
Milton Mass.

AL MILLEISEN, night foreman of our Cleaning and Assembly Department, who served as a First Lieutenant in the World War, is now in a new uniform. Two bars should be on his shoulder when this picture appears. If you took from the ranks of the allied armies those men who have already done their part, or who were Grade A exemptions, how much of the back-bones of those armies would be left. Al Milleisen is "back-bone" stuff wherever he is. We need more like him.

Now that we are using "Ersatz" and substitute alloys it is doubly important that engineering, metallurgy and foundry practice be maintained at the highest possible standards so that the utmost in service can be executed from the minimum of materials. General Alloys will deliver to you the maximum in service possible from the analyses permitted under government regulation.

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INSPECTION OF COPPER WELDS*

THE INSPECTOR should be familiar generally with the welding of non-ferrous alloys, methods of qualifying welding procedures and operators and methods of testing welds. He should also be familiar with the specifications or codes governing the particular work which he is to inspect. Some of the things to be observed are:

Appearance of Weld — The weld should have a neat appearance, be uniform in width and in height and contour of reinforcement. A localized increase in width of weld may mean excess heat at that point or an improper repair — covering up of a leak instead of gouging and rewelding.

Whenever possible, the inspector should examine the underside of a butt weld for correct penetration. Where too much metal has sagged through the joint (no back up) particular inspection should be given for a distance of approximately 2 in. each side of the icicle. Usually radial gas holes are present (particularly true with silicon bronze). The amount of sagging should not exceed $\frac{3}{16}$ in.

Undue distortion of the plates may mean improper jigging or indicate locked-up stress.

Undercutting, Cold Laps — As copper and high copper alloys are very fluid at fusion welding temperatures, there is some danger that the vertical face of an arc fillet weld may be undercut and undercutting may also occur on the far side of a vertical gas butt weld. Cold laps may occur on the front edges of a vertical butt or fillet weld and on the lower surface of a horizontal gas or arc fillet weld.

Cracks, Unsoundness — As in ferrous metals, internal cracks and unsoundness will be spotted most effectively with the X-ray. However, the inspector can generally detect any serious defect of this character. Cracks coming to the surface can generally be spotted. A 7 or 10-power hand magnifying glass is a distinct aid in such inspection. Where there is any doubt a chip taken with a round nose chisel driven along the center line of the supposed crack will decide. If the chip separates like a ram's horn, the crack is proved.

A similar test at the edge of the weld will prove correct or inadequate fusion.

Cracks may sometimes be

(Continued on page 104)

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*From copyrighted pamphlet entitled "Tentative Recommended Practices for Inspection of Fusion Welding", prepared by a committee of the American Welding Society, April 1, 1942.

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by Harry B. Pulsifer, Metallurgical Engineer, American Metal Treating Co., and Consulting Metallurgist, Ferry Cap and Set Screw Co., Cleveland, Ohio.

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Chapter One gives a brief review of what the steel maker aims to produce and how his best efforts may be frustrated by factors beyond his control. Remaining chapters enumerate various tests that can be made . . . the technique of making them . . . and how the results may be interpreted in terms of metal quality and utility. Many illustrations are used to clarify the particular details.

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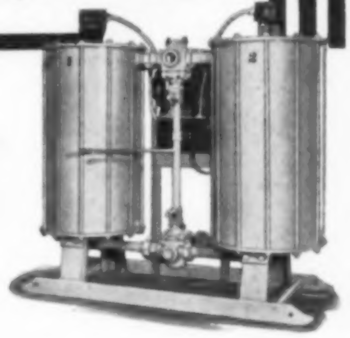

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WELD INSPECTION

(Continued from page 102)

spotted by the kerosene-chalk test, made by flooding the suspected surface with kerosene. After draining, the surface is covered with a mixture of chalk powder in water or whitewash. After this is dried the kerosene in the cracks will be absorbed by the chalk and discolor it. This test should be undertaken only by one who is familiar with the technique of carrying it out properly.

The gouging chisel is also useful in proving or disproving gas porosity. If there is any suspicion of unsoundness, a chip may be taken and the chipped surface inspected as well as the fracture at the end of the chip for porosity.

If any cracks or unsoundness is discovered in a weld in a pressure vessel, the same should be chipped out and rewelded. Weeps in copper alloys do not corrode tight as is often the case in ferrous welds. Caulking is also unsatisfactory in closing up minute porosity in copper or copper alloys.

Oxidized Weld Metal—A heavy black scale on the weld surface may indicate undue exposure of the metal at high temperature. Oxide in the metal is usually indicated by brittleness in the weld metal. It is rarely found in copper-silicon or copper-zinc alloys but may occur in arc welded copper mostly in the top of the bead or in gas welded electrolytic copper in a narrow zone at the edge of the weld. It may occur in phosphor bronze or the cupro-nickels if there is an inadequacy of the deoxidizer in the filler rod, and in aluminum bronze it may occur as a thin web which interrupts the continuity of the fused metal.

In any case, the oxidized metal can usually be spotted by chipping the location and noting the ductility as indicated by the chip. Oxidized metal will break off short while clean metal will show a reasonable degree of ductility.

Entrapped flux will usually occur, if at all, in the area at the edge of the weld. It can be discovered only by chipping or with the X-ray.

Silver brazed or soft soldered copper or brass tube in wrought copper or cast brass fittings must be inspected by the appearance of the metal and the solder fillet as to whether the job has had the correct temperature. In butt welded or bell and spigot brazed (bronze welded) brass or copper pipe, the appearance of the weld is usually sufficient evidence of a workmanlike job, though the inspector can spot "icicles" under the butt joint only by looking or feeling inside the pipe.

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CONTRIBUTORS TO THIS ISSUE

MEMBERSHIP on six committees, including chairmanship of three of them, keeps **John Mitchell**, alloy metallurgical engineer for Carnegie-Illinois Steel Corp., extremely busy and very well informed on problems of alloy selection and conservation. As chairman of the Chrome-Nickel Alternate Steels Committee of the American Iron and Steel Institute, he has helped establish standard specifications for 16 National Emergency steels, and as chairman of the W.P.B. Technical Advisory Committee on Carbon and Alloy Steel Bars and Billets, he directs the activities of five groups working on industrial applications of these NE steels. He is also chairman of the Alloy Technical Committee (Technical Standardization) of the A.I.S.I., and a member of the W.P.B. Technical Advisory Committee on Aeronautical Steels, and of the Small Arms Technical Committee and the Armor Piercing Shot Committee of the Army Ordnance Department. Mr. Mitchell also has to his credit numerous metallurgical and technical developments making possible use of steel sheets in airplane construction to conserve aluminum and other strategic materials.

Thomas D. Jolly, chief engineer and director of purchases, has supervision over the entire 250 million dollar expansion program of the Aluminum Co. of America, as well as the 15 plants under construction for the Government's Defense Plant Corp. He began with the Aluminum Co. as a draftsman after being trained in mechanical engineering at Carnegie Institute of Technology. Except for 18 months' service with the Engineers' Corps during World War I, he has been with Alcoa ever since, serving successively as machine designer, master mechanic, superintendent of maintenance, mechanical superintendent, buyer and purchasing agent. He was promoted to his present position in 1937.

Lieut. **G. J. Foss**, Jr. has a B.S., M.S. (magna cum laude), and Ph.D., all from University of Notre Dame, where he was a graudate assistant and teaching fellow from 1935 to 1940. He has also been employed by Carnegie-Illinois Steel Corp. South Works, by the Sanitary District of Chicago, and has been instructor at Catholic University of America. He has been on active duty in the Navy since June 1940 in the Metallurgical and Testing Section at Washington. He was secretary-treasurer of the Notre Dame Chapter ⊕ for four years.

Larry Shiller has been at the Washington Navy Yard since 1939, first in the physical testing laboratory, then in the magnetic inspection division, and finally in the metallographic laboratory, where he has specialized particularly in cartridge brass and cartridge cases. He has a degree of Bachelor of Science in Mechanical Engineering from University of North Carolina.

Milton Clayton Shaw was born in Philadelphia and studied at Drexel Institute of Technology, receiving a B.S. in Mechanical Engineering in 1938. As a Cincinnati Milling Machine Co. fellow at University of Cincinnati from 1938 to 1942, he received a Master of Engineering Science degree and a Doctor of Science degree. He was employed as research engineer at the Cincinnati Milling Machine Co. before being called to his present position in the Fuels and Lubricants Section of the National Advisory Committee for Aeronautics at Langley Field, Va.

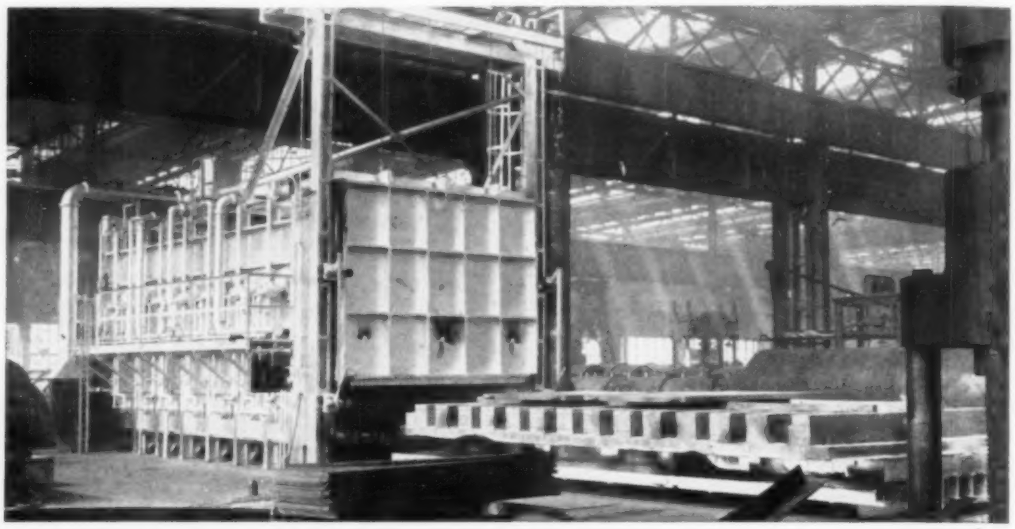
Thomas D. Jolly

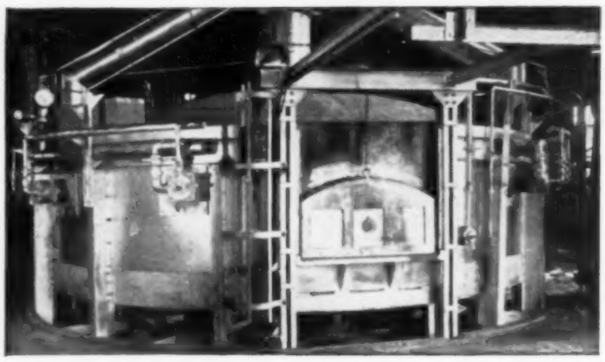
Milton C. Shaw

G. J. Foss, Jr.

Larry Shiller

John Mitchell





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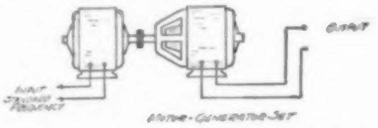
Subject: Production and Control of High Frequency Magnetic Fields **Sheet No. 2**

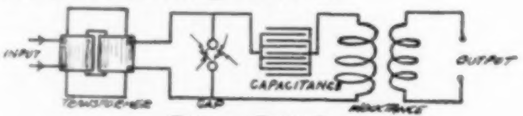
SOURCES OF HIGH FREQUENCY ELECTRICAL ENERGY

In Data Sheet #1, it was shown that in order to raise the temperature of a material by induction heating, it was necessary to place it in a high frequency alternating magnetic field. Hence, our next consideration should be the methods of magnetic field production. There are three available sources of electrical energy at frequencies, and with capacities, suitable for commercial induction heating; the rotating electrical generator, the resonant spark-gap circuit, and the vacuum tube oscillator. These sources cover a frequency range from 1000 cycles to 5 megacycles. Each method has its inherent advantages and disadvantages. A brief discussion of this is in order.



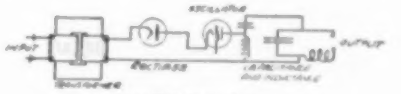
MOTOR-GENERATOR SET

The rotating electrical generator has a distinct advantage of being available at capacities up to 250 kw output, and consequently, large energy requirements can be met. However, its frequency range is limited by mechanical design, with a maximum of approximately 15 kilocycles. Therefore, even though having a large capacity, the energy available in producing a magnetic field is limited by the comparatively low frequency. This method also carries with it the maintenance problems of high speed rotating machinery and presents a low overall efficiency due to the friction and windage losses. Because of the low frequency, inductive loads placed across the terminals of the generator have a comparatively low impedance and, therefore, do not require high terminal voltages. The cooling system employed with this type of generator is usually forced air circulated by a fan attached to the shaft of the motor-generator set.



RESONANT SPARK GAP

The resonant spark-gap circuit for producing high frequency consists fundamentally of a step-up transformer converting standard frequency low voltage energy into energy at a potential of the order of 3000 volts. Across the terminals of the step-up transformer is a circuit consisting of a spark-gap, capacitance, and inductance; the ratio of capacitance to inductance, along with the spark-gap characteristics, determining the frequency at which the current flows in the closed circuit. The output of this type of generator is usually taken from a second inductance coil magnetically linked with the main inductance of the circuit. The physical size of the inductance and capacitance going to make up the constants of this circuit set the frequency limits between 80 and 200 kilocycles. These same quantities also limit the output capacity of these generators to approximately 20 kw. As the higher frequencies are approached, more critical matching of the output load is required and hence the coupling between the primary and the secondary inductances is usually variable to accomplish this result. Units of this type have the advantage of being static and fundamentally simple in construction. They have limited output, however, and the maintenance of the spark-gap for uniform frequency control is considered by most users as a distinct disadvantage. Various types of spark-gaps are used; some being air gaps while others operate in an inert atmosphere, but regardless of these differences, periodic reconditioning is essential.



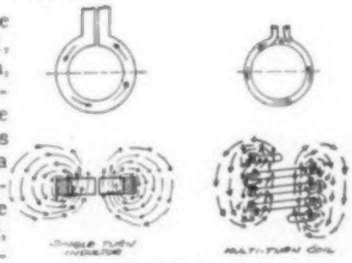
VACUUM TUBE OSCILLATOR

The third method producing high frequency electrical energy is the vacuum tube oscillator which depends upon the characteristics of electronic tubes in producing rapid electric pulsations. This equipment also consists of a capacitance and inductance; the output frequency depending only upon the ratio of the value of these two constants. The usual method is to employ three-element vacuum tubes as oscillators being fed through a bank of mercury-vapor rectifiers. The fundamental circuit takes low voltage alternating current and steps it up to approximately 10,000 volts; this voltage being in turn rectified into a full wave dc potential. This potential is used to charge a capacitance through the oscillator tube circuit. The discharge current from the condenser passes through the inductive shunt circuit in series with which are the output terminals of the generator. Frequencies ranging from 200 kilocycles to 5 megacycles may be obtained with units of this type depending upon the electronic tubes employed and the circuit constants. These units are entirely static in operation and are fixed frequency generators. Their physical size is relatively small per kw capacity and the input power factor is practically unity. The vacuum tubes have shown their ability in radio broadcast services to give service for 10,000 to 15,000 hours. However, the tubes have the disadvantage of requiring water cooling. This, on the other hand, is relieved somewhat by the fact that the high frequency leads and coils in practically all types of induction heating equipment necessitate water cooling, and the same water used for this purpose can also be used to cool the tubes.

PRODUCTION AND CONTROL OF MAGNETIC FIELDS

After obtaining a source of high frequency electrical energy by any of the above mentioned methods, the next problem on hand is the design of a conductor set-up which will give the proper heat producing magnetic field. As defined in our previous data sheet, "magnetic fields occur in the area surrounding a current carrying conductor", and "the strength of the field varies inversely as the square of the distance from the current-carrying conductor". Since the prime purpose of using induction heating is to localize heat to a certain specified section, we must produce a magnetic field which follows the depth and contour of this section. Consequently, we must locate current carrying conductors which will produce a magnetic field meeting these requirements, and having sufficient field strength to give the desired heating effect.

The usual form of these conductors is a coil, either single or multi-turn, depending upon the flux-pattern requirements. Since field strength depends upon the current in a single-conductor, its magnitude is amplified by the use of a multi-turn coil, each turn acting individually as a conductor. The sketch above shows the flux-patterns of the magnetic fields surrounding both single and multi-turn coils, with no metallic material in the coil.



MAGNETIC FLUX PATTERNS
NO WORK IN COILS

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INDUCTION HEATING CORPORATION
Designers • Builders • Of Thermonic Heat Treating Equipment
389 LAFAYETTE STREET, NEW YORK CITY, N. Y.

THIS IS THE SECOND OF A SERIES OF DATA SHEETS COVERING THIS IMPORTANT SUBJECT. SAVE IT FOR
YOUR PERSONAL FILE. A REQUEST ON YOUR BUSINESS STATIONERY WILL BRING YOU A BINDER

NEW PRODUCTS AVAILABLE

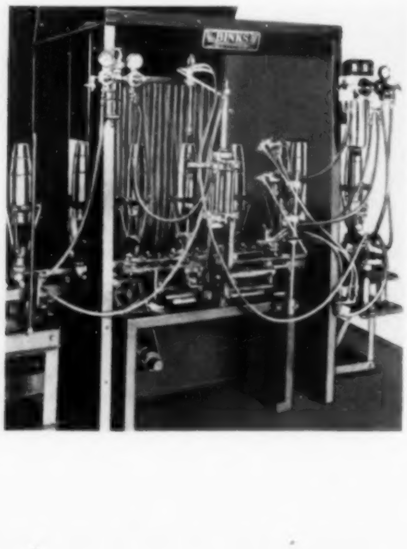
Stopper Head

Perfected by ceramic engineers of the Electro Refractories and Alloys Corp., Buffalo, N. Y., working closely with steel plant metallurgists. Requirements: High resistance to abrasion, high softening point, spalling resistance, supply not threatened by shortage of critical materials. (No. 63)

ELECTRO
REFRACTORIES
BUFFALO N.Y.
10

Shell Coating

Machine sprays automatically the inside and outside of 75 mm. to 105 mm. shells at the rate of 200 to 500 per hr. Shells are loaded on moving conveyor and are rotated in front of spray guns which spray the exteriors. Still rotating, the shells pass to a position where a gun is lowered into the interior, thus completely spraying the inside. Binks Mfg. Co., Chicago. (No. 64)

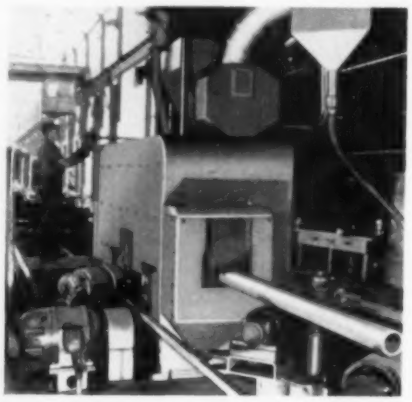


Stabilizing Control

Development in the field of control engineering has been announced by the Foxboro Co., Foxboro, Mass., under name of Hyper-Reset. Not an instrument or a mechanism, this is a control function available in Model 30 Stabilog Controller, for application where process-lag is considerable. Hyper-Reset reduces the effects of a disturbance by making temporary additional corrections, proportional to the rates of change of the measured value caused by the disturbance. The normal reset follows, thus reestablishing stable conditions. (No. 65)

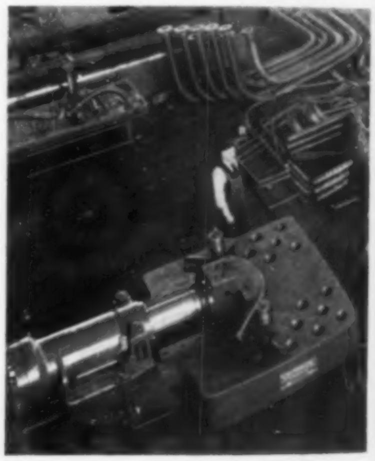
Removing Scale From Pipe

Equipment for removing heavy furnace scale from seamless steel pipe, shown in the view, includes an airless Wheelabrator for cleaning the exterior of pipe varying from 2 to 14 in. o.d. and from 18 to 50 ft. in length. An air blast is used for descaling the interior. In continuous production, cleaning speeds vary according to size of pipe, type of steel and condition of scale. For example, speed of the conveyor rolls for 4½ in. standard low carbon pipe is 18 ft. per min. for the exterior and 14 ft. for the interior. Built by American Foundry Equipment Co., Mishawaka, Ind., for the National Supply Co. (No. 66)



Pipe Bending Press

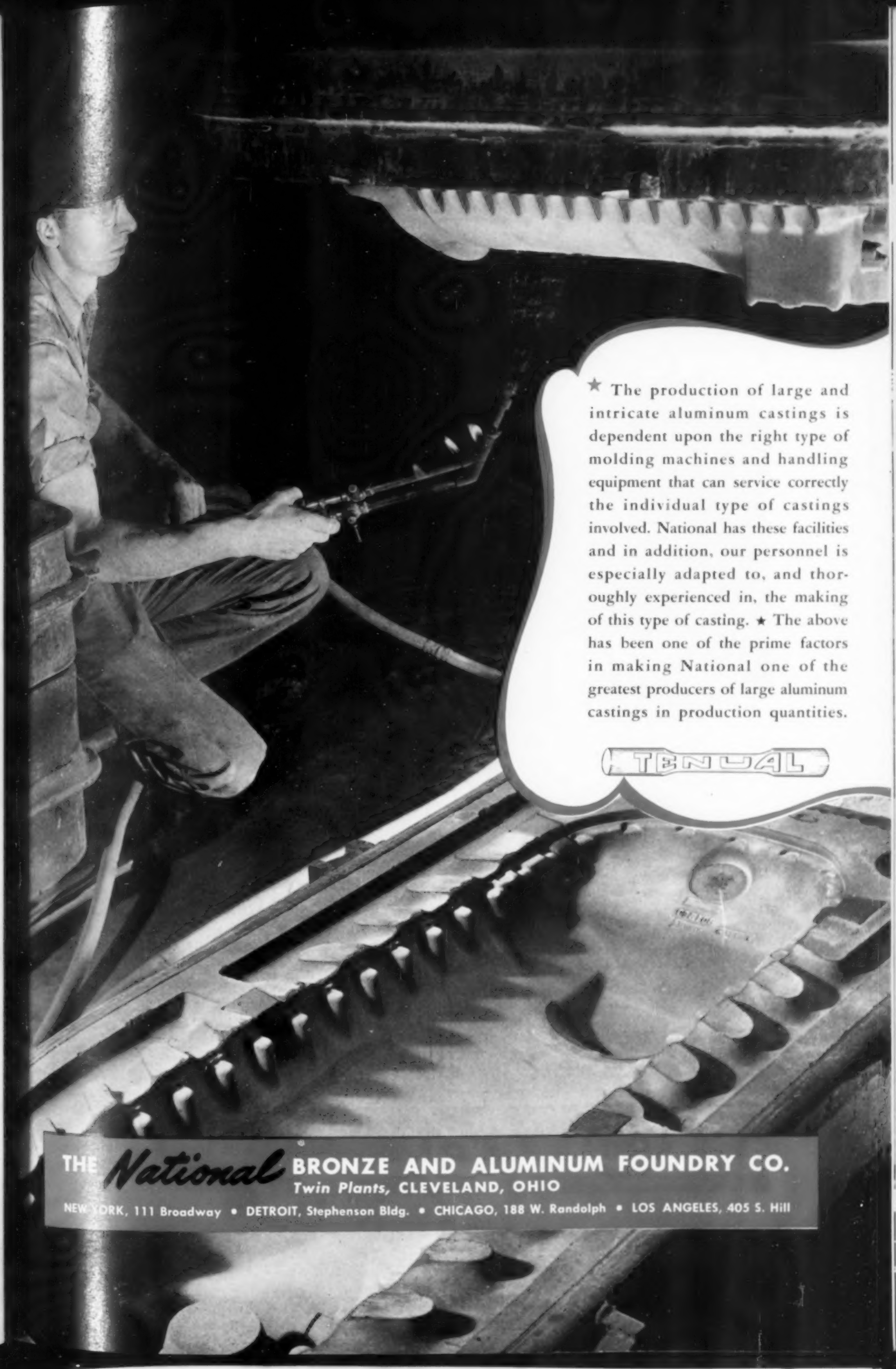
200-ton hydraulic pipe bending press saves time usually required to heat pipe by making many bends cold. This also eliminates distortion in the shape when cooling. Manufacturer is the Baldwin-Southwark Division of Baldwin Locomotive Works, Philadelphia. (No. 67)



Anodic Degreasing Material

Specially designed to meet war demands for faster cycles in anodic degreasing or reverse current cleaning of cold rolled steel parts before finishing, an alkaline-type material has just been announced by Oakite Products, Inc., N. Y. City. *(Cont. on p. 118)*

Readers may obtain complete details on these products by writing to the manufacturer direct, or to Metal Progress. We will gladly pass requests on to the manufacturer. Simply mention the paragraph numbers of the items in which you are interested.



★ The production of large and intricate aluminum castings is dependent upon the right type of molding machines and handling equipment that can service correctly the individual type of castings involved. National has these facilities and in addition, our personnel is especially adapted to, and thoroughly experienced in, the making of this type of casting. ★ The above has been one of the prime factors in making National one of the greatest producers of large aluminum castings in production quantities.

THE *National* BRONZE AND ALUMINUM FOUNDRY CO.
Twin Plants, CLEVELAND, OHIO
NEW YORK, 111 Broadway • DETROIT, Stephenson Bldg. • CHICAGO, 188 W. Randolph • LOS ANGELES, 405 S. Hill

PRODUCTS

(From page 116) Known as Oakite Composition No. 90, it has high conductivity, is adaptable to hard water, has smut-removing properties and fast wetting-out action. It removes oil, grease, smut, polishing and buffing compounds on a wide range of war supplies. (No. 68)

Cold Producer

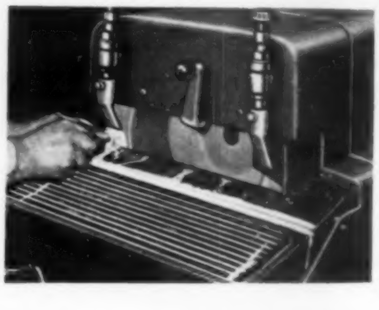
Temperature as low as –50 to –80° F. for testing, shrinking or "heat treating" parts, materials and machinery, and for other experimentation, is provided by the Niagara No-Frost Method. Ice or frost does not form on cooler coils to interfere with operation of this equipment, which uses no brine but a special non-freezing liquid. Niagara Blower Co., N. Y. City. (No. 69)

Arc Welder

Heavy duty, air-cooled arc welder, known as the 250 F, has been developed by Ergolyte Mfg. Co., Philadelphia. War-time demand for virtually continuous welding prompted its development to avoid early burning out which is almost certain to result under present high-pressure operation of older equipment. New machine supplies current for electrodes from $\frac{1}{16}$ to $\frac{3}{16}$ in., has 24 heat steps, an input voltage of 230 volts and current range from 15 to 250 amperes. (No. 70)

No-Splash Carbide Tool Grinder

These 10 and 14 in. wet or dry carbide tool grinders have been designed with new no-spray, no-splash guards. Provide greater accuracy and much faster operation because the extra working spaces around the grinding wheels permit the maximum amount of light and fullest operating freedom — unhampered by hoods or shields. Manufactured by Hammond Machinery Builders, Kalamazoo, Mich. (No. 71)



Holding Magnet

Electro magnets are finding numerous applications in such fabrication industries as shipbuilding and are used extensively in welding assemblies for drawing and holding plates together. Stearns Magnetic Mfg. Co., Milwaukee, makes a magnetic welding clamp in various sizes for such use. Plates are drawn to a level alignment with the edges flush against the flat surface of the magnet. (No. 72)

Spring Retainer Shaft

IT'S MADE OUT OF
SPEED CASE STEEL
A LOW CARBON OPEN HEARTH PRODUCT

—because . . .

It saved $37.50 per ton of steel used
It machined faster than SAE 1112
It increased tool life 45%
It riveted without fracture

Ductility
Plus
Machinability
(230 SFPM)

Speed Case will rivet • Bend cold 180° 1" Rd. C. D.
Machines at 230 SFPM • Very smooth finish
Excellent carburizing

In this "all-out" war effort Monarch Steel is co-operating 100%.
We're helping to "keep 'em rolling" with Speed Case Steel.

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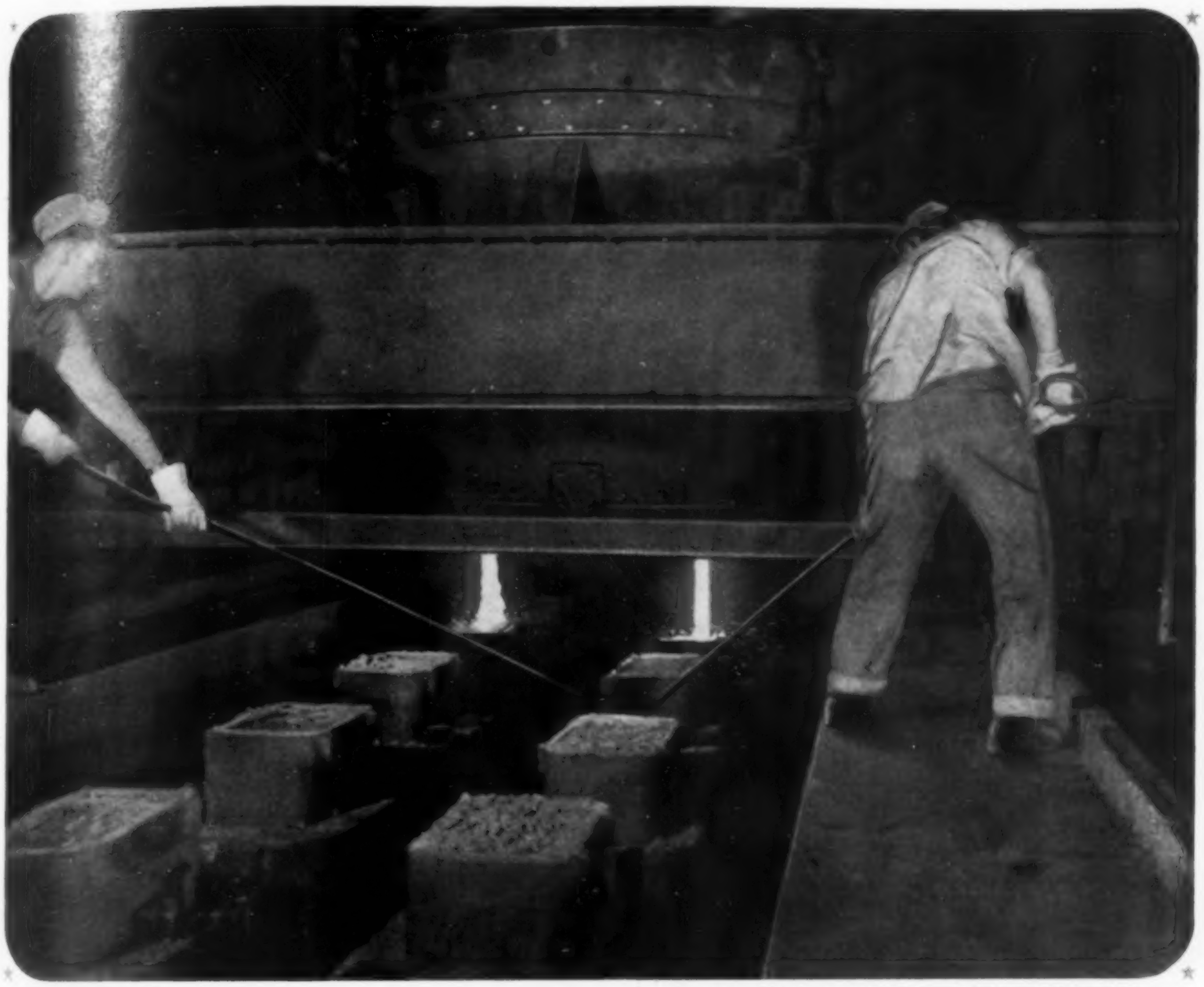
YOUNGSTOWN, OHIO

MANUFACTURERS OF COLD FINISHED CARBON AND ALLOY-STEEL BARS



O E M Photo by Palmer, in an Allegheny Ludlum plant

STEEL IS FLOWING TODAY THAT WILL BE FLYING NEXT MONTH

Alloy steel, conceived in the mighty heat of electric furnace arcs, is just being born when it teems into ingot molds.

How soon can the raw steel in those ingots be brought to maturity as parts in finished warplanes (or tanks, guns, ships, munitions)? How much of it can be actually put to work, with only a bare minimum of scrap, "reject" and spoilage losses? In this war, a battle easily may hang on the way any one plant handles its problems of production and conservation.

The Allegheny Ludlum line-up of alloy war-steels includes stainless and heat resistant, tool, valve, nitriding and electrical steels. Information on their more effective fabrication and use includes certified "Blue Sheets" for engineers and technical men; "Handbook of Special Steels" for production men; "Elementary Discussions" of tool and stainless steels for training course use, etc.

● Tell us your alloy steel problems—particularly if yours is a converted plant, making unfamiliar products from strange materials. If we don't have the answers in printed form, the services of our Technical and Field Staffs are also at your disposal.

AL
STEEL FOR THE NATION'S WELFARE

Allegheny Ludlum
STEEL CORPORATION
GENERAL OFFICES: PITTSBURGH, PENNSYLVANIA

AUSTENITIC STRUCTURE*

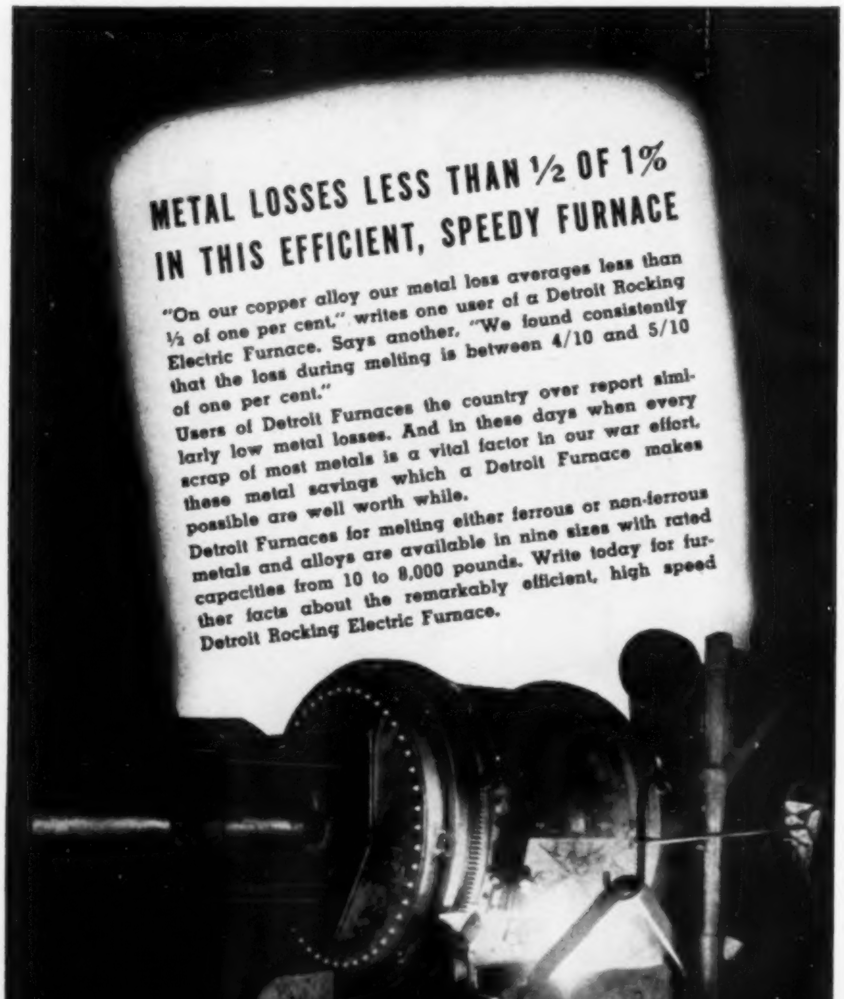
By N. J. Petch

PUBLISHED INFORMATION about the crystallographic nature of austenite has been reviewed and it was concluded that the weight of evidence was in favor of the view that on heating through Ac_{1-3} the complicated orthorhombic crystals of cementite lost their identity, the individual atoms of carbon taking up positions in the spaces between the iron atoms (that is, forming an interstitial solid solution). A cogent argument is that when the carbon atom crowds itself into a gap of this sort the iron atoms will be forced slightly apart, and the lattice correspondingly expanded — which agrees with actual density measurements.

Investigation of the problem by X-ray diffraction analysis has been difficult because the small carbon atoms themselves have little effect on the intensity of X-ray reflections as compared with the reflections from the iron atoms. It may also be computed that, in a 1.4% carbon austenite, the intensity of reflections from important crystal planes is changed by no more than 2% (whereas the experimental accuracy of the most careful measurements approaches 1%).

The iron atoms in the face-centered austenite lattice may be looked upon as arrangements of regular octahedra or regular tetrahedra, and the centers of either may be a space wherein an iron atom may lodge. In the first case the reflection from the 111 plane of the given 1.4% carbon austenitic steel would be decreased by about 2%, while in the second case the reflection from the same plane would be unaffected; reflections from the 200 plane would be increased by about 2% under the first assumption, and decreased by 2% under the second; and so on. Using a very pure iron alloy of 13% manganese and 1.43% carbon, heat treated and quenched in vacuo from 1900° F., and showing only austenite lines, expected approximate deviations of the seven lines that could be measured accurately were actually found, and *always* in the correct direction (plus or minus) as predicted when the carbon atoms are surrounded by six equidistant iron atoms.

In other words, the carbon atoms lie at the centers of the unit cells and at the mid points of the edges.



METAL LOSSES LESS THAN ½ OF 1% IN THIS EFFICIENT, SPEEDY FURNACE

"On our copper alloy our metal loss averages less than ½ of one per cent," writes one user of a Detroit Rocking Electric Furnace. Says another, "We found consistently that the loss during melting is between 4/10 and 5/10 of one per cent."

Users of Detroit Furnaces the country over report similarly low metal losses. And in these days when every scrap of most metals is a vital factor in our war effort, these metal savings which a Detroit Furnace makes possible are well worth while.

Detroit Furnaces for melting either ferrous or non-ferrous metals and alloys are available in nine sizes with rated capacities from 10 to 8,000 pounds. Write today for further facts about the remarkably efficient, high speed Detroit Rocking Electric Furnace.

DETROIT ELECTRIC FURNACE DIVISION
KUHLMAN ELECTRIC COMPANY • BAY CITY MICHIGAN

---

*Abstract of "The Positions of the Carbon Atoms in Austenite", paper for the Feb. 1942 meeting of the British Iron & Steel Institute.

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gricultural Machinery
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veyor & Material Handling
hing Machinery & Cement Mill
dge
ctrical Machinery & Equipment
vator
gine
d Processing & Packing Plant
dry Machinery & Equipment
Producer & Coke Oven
ars
t Treating Furnace & Equipment
t & Derrick
Iron & Steel Industries
Metallurgical Machinery
Mining Machinery & Equipment
Oil or Gas Field & Refinery
Ordnance
Overhead Crane & Charging Machine
Paper Mill
Printing Press
Pump
Railroad
Refractory, Brickyard & Ceramic
Refrigeration Machinery
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Spray Painting Equipment
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Detroit, Michigan
Detroit Steel Casting Company
4069-4140 Michigan Avenue LAfayette 5710

Houston, Texas
Texas Electric Steel Casting Company
Bringhurst & Gillespie. Fairfax 8117

Indianapolis, Indiana
Electric Steel Castings Company
Speedway. Belmont 0400

Milwaukee, Wisconsin
Sivyer Steel Casting Company
1675 S. 43rd St. MItchell 1442

Newark, New Jersey
American Steel Castings Co.
Avenue "L" and Edwards Street Market 3-5464

Philadelphia, Pa.
Dodge Steel Company
Tacony. MAYfair 1650

Toledo, Ohio
Unitcast Corporation, Steel Casting Division
Front and Millard Avenue POntiac 1545

Tulsa, Oklahoma
Oklahoma Steel Castings Company
1200 N. Peoria. 5-9286

COMPUTING HARDENABILITY

(Continued from page 80)

in a size $0.24 \times 4 \times 1.10 = 1.055$ in., or about $1\frac{1}{16}$-in. round, in the ideal or instantaneous quench.

Similarly the other elements, commonly determined, 0.020% phosphorus and 0.029% sulphur, introduce two more factors, 1.05 and 0.98 respectively, as determined by points *D* and *E* on the top right diagram in the data sheet. This steel, therefore, if appraised by the ordinary elements carbon, manganese, silicon, phosphorus and sulphur, would have an ideal diameter of

$$D_I = 0.24 \times 4 \times 1.10 \times 1.05 \times 0.98 = 1.085 \text{ in.}$$

However, the small amounts of the other elements existing in this steel (and in many steels sizable amounts are acquired from the scrap) more than double the hardenability. 0.28% nickel has a factor of 1.10 (point *F* in the middle right figure); 0.30% chromium introduces a large factor of 1.70 (determined at point *G*), 0.05% molybdenum a factor of 1.16 (point *H*) and 0.05% copper a factor of 1.02 (scaled from the line for nickel).

Multiplying all these factors for all the elements determined results in a figure of 2.40 for the ideal diameter of steel of the given analysis and grain size. As mentioned, this hardenability number states the size of bar that will just harden all the way through to a 50% martensitic microstructure in an ideal quench, as judged by fracture or etch test.

If it is desired to express hardenability in some other units, as for example the extent of hardening in a Jominy end-quenched bar, then the curve at lower left in the data sheet may be consulted. Ideal diameter 2.40 is noted on the curve at point *K*, which corresponds to ⅜ in. from the end of the end-quenched specimen. This means that the hardness of the center of the ideally quenched round bar will be found ⅜ in. from the end of the Jominy hardenability test bar. This actual hardness for the 0.50% carbon low alloy steel is about Rockwell C-45, as estimated from the curve at the lower left of the data sheet.

It should be strongly emphasized that when undissolved carbides are present in the steel as quenched, the charts can indicate only a maximum possible hardenability, whereas the extent of hardening actually obtained may be much less because of undissolved alloy and carbon. This situation is illustrated in

(Continued on page 126)

Photo by U. S. Army Signal Corps.
Built RIGHT!

with AMPCO Bronzes' Rugged Strength

Designing engineers—men who know materials—find need for Ampco Metal and Ampco-made bronzes in the vital instruments of war. In anti-aircraft gun mounts—in aircraft—in machine tools—bronzes from the Ampco foundries are in service.

TO GOVERNMENT SPECIFICATIONS

Much of the bronze cast at Ampco is to government specification. The wide experience of our engineers and metallurgists—skilled in producing bronzes to meet exacting conditions—is at the service of government contractors and others supplying essential equipment.

If you need a bronze that must meet definite physical properties and chemical composition, consult with Ampco. All alloys are laboratory controlled and closely inspected at every step with precision instruments. *Ask for literature.*

AMPCO METAL, INC.
DEPARTMENT MP-7 MILWAUKEE, WISCONSIN

AMPCO METAL
AMPCO
THE METAL WITHOUT AN EQUAL

DESPATCH
DESPATCH OVEN CO.

OFF TO THE PRODUCTION FRONT *in record time*

To Fight This WAR OF METALS—

PHONE OR WIRE TODAY FOR A DESPATCH ENGINEER!

DESPATCH POT TYPE FURNACES

For annealing steel shell cases, brass shell cases, for tempering gun parts, tools and dies, armor piercing shot, precision instruments and other processes necessary to the production of war equipment.

SHIPPED IN 6 WEEKS

DESPATCH CONTINUOUS CONVEYOR FURNACES

For treating armor plate, annealing steel shell cases, brass shell cases, for heat treatment of small arms, such as, guns, rifles, machine guns, automatic pistols, revolvers and parts; also for tempering tools and dies.

SHIPPED IN 8 WEEKS

DESPATCH ALUMINUM AND MAGNESIUM HEAT TREATING FURNACES

For solution heat treatment, precipitation heat treatment of aluminum alloy and magnesium alloy castings, forgings, sheets and shapes. For heat treatment of other semi-finished products of aluminum, copper, brass, steel, etc., in the form of sheets, strips, castings, tubing. Also for stress relieving welded structures for gun carriages, welded tanks and tank parts.

SHIPPED IN 9 WEEKS

DESPATCH

OVEN COMPANY MINNEAPOLIS, MINNESOTA

Conserving Nickel and Chromium Through Proper Care

Heat resistant alloys are indispensable in many of our war production processes, because they resist oxidation and retain their strength at high temperatures definitely better than other commercial metals. Nevertheless, regardless of who makes them, they are metals which expand and contract with changes in temperature. They can be overheated and, therefore, with proper care, can be made to last longer.

Nickel and chromium, which are the major constituents of these alloys, are critical materials in our Victory program and the supply is limited. Also, they are relatively expensive metals. Obviously, then it is essential that special precautions be taken concerning the service condition under which the heat resistant alloys are used, to insure their conservation and for economy as well. In the fever of high pressure production there is always the possibility of neglect and abuse.

The following safeguards therefore should be very carefully observed:

1. Avoid overheating.
2. Avoid localized or uneven heating.
3. Regulate changes in temperature as much as process will permit.

Use of the proper analysis for the job is vitally important and Amsco, through its metallurgical and physical research laboratories, can aid materially in the selection, and through its engineers, help develop proper designs that take into consideration thermal stresses, shape of parts to be heat-treated and other pertinent factors.

Amsco Alloy is serving production for Victory in many plants employing heating, heat-treating, roasting, refining, calcining and other processes requiring high temperatures and involving corrosion.

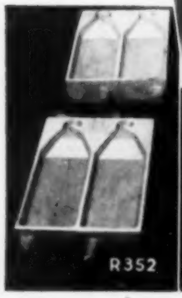
Bulletin 108 describes the standard analyses of Amsco Alloy and pictures typical heat and corrosion resistant castings for industry.

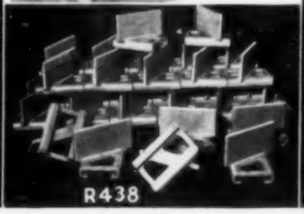
R375—Discharge spout for bolt heat-treating furnace.

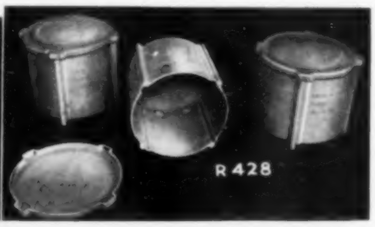
R352—Amsco Alloy molds for dore (a composition of silver and gold) made for metals refiner.

R438—Ore roasting furnace rabble blades of Amsco Alloy grade F-3.

R428—"Flexboxes"; carburizing containers sectionalized to compensate for expansion and contraction. Any of the four sides, bottom or cover can be replaced separately.







Amsco

AMERICAN MANGANESE STEEL DIVISION
OF THE AMERICAN BRAKE SHOE & FOUNDRY CO.
Chicago Heights, Illinois

Manganese Steel Castings for shocks and abrasion.
Chromium-Nickel Alloy Castings for heat and corrosion resistance.
Power Shovel Dippers. Dredge and Industrial Pumps.
Welding Materials for reclamation and hard-surfacing.

FOUNDRIES AT CHICAGO HEIGHTS, ILL.; NEW CASTLE, DEL.; DENVER, COLO.; OAKLAND, CALIF.;
LOS ANGELES, CALIF.; ST. LOUIS, MO. OFFICES IN PRINCIPAL CITIES

HARDENABILITY

(Starts on page 80)

the hatched areas above the chromium and vanadium lines. Especial care is necessary in computing hardnesses of steels like chromium-molybdenum S.A.E. 4150.

The ideal diameter D_I denotes (as mentioned previously) the size of bar that just hardens to a half-martensitic core in an ideal (severest possible) quench. Actual quenches in practice are less drastic than the ideal quench, so that the size that will just harden fully is smaller than the ideal diameter D_I. The size that just hardens in any actual quench may be predicted by the use of the lower right diagram in the data sheet, after some information has been gained as to the actual severity of quench. It is easy to ascertain the severity of quench experimentally, as shown in the data sheet, Metal Progress for October 1941, page 520, or the figures in the table may be used as a guide.

Assume that the steel in question (ideal diameter 2.40) is to be quenched in water, mildly agitated. The severity of such a quench (*H* value from the table) is 1.05. The actual critical diameter for full hardening under these circumstances would be scaled to the left from point *M*, and is about $1\frac{9}{16}$ in.

As to the reliability of the method, the experimental result checks with the calculated usually within 10 or 15% when precise data are available, and under more ordinary conditions mostly within 15 to 20%. When it is realized that a difference of only one grain size number will modify the results by almost 10%, and that a so-called "incidental" chromium content of 0.20% increases hardenability by about 50%, it will be realized that an agreement within 10 to 20% will possibly be an adequate guide for most purposes. ●

BETTER PERFORMANCE
FOR
QUICKER VICTORY

ANNEALING EQUIPMENT

by the

PRESSED STEEL COMPANY

Pressed Steel Company Radiant Tubes and round and rectangular Annealing Covers recently installed at
THE SUPERIOR STEEL CORPORATION
Pittsburgh, Pennsylvania

This installation was made by The Lee Wilson Engineering Company of Cleveland, Ohio

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of WILKES-BARRE, PENNSYLVANI

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PRESSED STEEL COMPANY PRODUCTS: Carburizing and Annealing Boxes, Thermocouple Protection Tubes, Seamless Steel Cylinder Caps, Seamless Steel Neck Rings, Welded Alloy Tubing for High Temperature and Corrosive Application

WELDABILITY OF SUBSTITUTES

(Continued from page 71)

2100° F., air cool one, cool one by air blast and one by oil dip. The width of the bars is preferably $1\frac{1}{2}$ times or more than the thickness, and they should be long enough for convenient bend test. After heat treatment, measure the hardness of the bars, cut a standard notch across one face of each, bend and measure the angles. Interpolate for the angle corresponding to that hardness measured in Item 1. This is an index of ductility and weldability as far as heat effect next to the weld is concerned.

4. Run a Jominy end-quench test on the new steel using procedure identical to that in Item 2. Measure hardness at that distance from the end determined in Item 2. This gives hardness to be expected in the welding operation.

5. Prepare two or three bend bars of the new steel identically as in Item 3, and subject to the same procedure. Interpolate for angle of bend corresponding to that hardness determined in Item 4. Comparison of this angle of bend and the angle of bend found in Item 3 gives relative weldability under the specific conditions pertaining to the joint selected in Item 1.

To illustrate this system a comparison was made of steel NE 8630 with S.A.E. 4130 used in a joint comprising a single layer fillet tee weld made by the metallic arc on $\frac{3}{4} \times 2\frac{1}{4}$-in. plates. In this weld $\frac{3}{16}$-in. carbon-molybdenum electrodes were used with welding current of 160 amperes. Fillet was $\frac{5}{16}$ in. on edge.

In line with Item 1 the weld was sectioned, lightly etched to disclose the boundaries of the heat-affected zone and maximum hardness measured as Rockwell C-40. In line with Item 2, a $\frac{3}{4}$-in. round bar 3 in. long of the S.A.E. 4130 steel was end-quenched after heating for 1 hr. in cast iron chips. Hardness readings taken along the bar showed that C-40 hardness, obtained in Item 1, occurred 0.338 in. from the quenched end. In line with Item 3, three test bars $\frac{1}{2} \times 1\frac{1}{2} \times 6$ in. of the S.A.E. 4130 were heated to 2100° F. and cooled in still air, in an air blast and in oil, respectively. Hardness was measured, a standard Izod notch cut across each bar face and the bars bent to initial failure. The angles were measured and by interpolation it was determined that 4° bend corresponded to hardness C-40.

In line with Item 4, a bar of the NE 8630 identical in all respects except composition with

(Continued on page 138)

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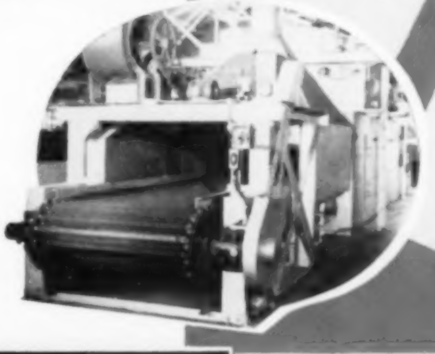

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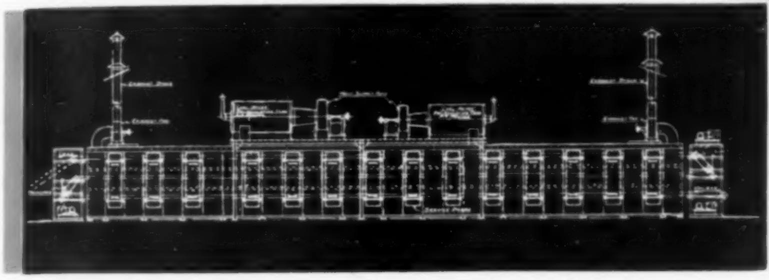

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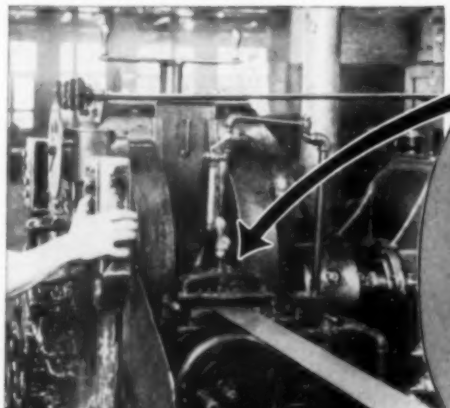

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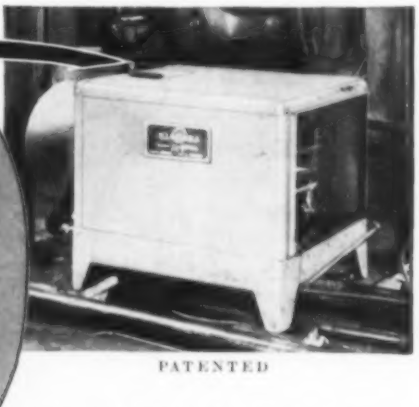

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WELDABILITY OF SUBSTITUTES

(Starts on page 71)

that used in Item 2 was subjected to the same end-quench procedure. At the distance of 0.338 in. determined in Item 2, hardness of the NE 8630 steel was C-43, in line with Item 5. The procedure in Item 3 was then duplicated, using NE 8630 steel and the bend angle of 4.3° was found to correspond with a hardness of C-43.

From the above data, tabulated at right, it was concluded that the weldability of the two steels was practically identical as concerns the heat effect next to the weld in the joint in question.

To check this conclusion a weld was made in the new steel, attempting to duplicate all conditions of welding. The weld was sectioned and a maximum Rockwell hardness of C-40.5 was found. It should be noted that C-43 was predicted. The difference is minor and may well have resulted from small variations that are to be expected in hand welding. Both this weld and the weld made in the standard steel used in Item 1 were then notched in such manner as to place the bottom of the notch at the zone of maximum hardness. The joints were then bent and the angles measured. The angle of bend was identical for the two steels — namely, 5.5°.

	"STANDARD" S.A.E. 4130	"NEW" NE 8630
Hardness near weld	C-40	
Jominy test for C-40	0.338 in.	
at 0.338 in.		C-43
Bend	4°	4.3°

It should be noted that only the relative difference between the two welds is of interest, and that there is no reason to expect the angle of bend in the weld proper will be the same as that in the test specimen. This is due to the fact that the hardness of the test specimen is the same throughout, whereas the hardness adjacent to the weld drops off rapidly from the maximum.

The important thing is that the bend values of the two steels are the same, both in the test specimens and in the welds proper, thus confirming the prediction that the weldability of the new steel is substantially the same as the standard steel as far as heat effect next to the particular weld in question is concerned.

It must again be emphasized that the procedure described applies to weldability only as regards the heat effect of welding on the base metal. If other factors are involved the reader should refer to the more comprehensive paper above cited. ◆

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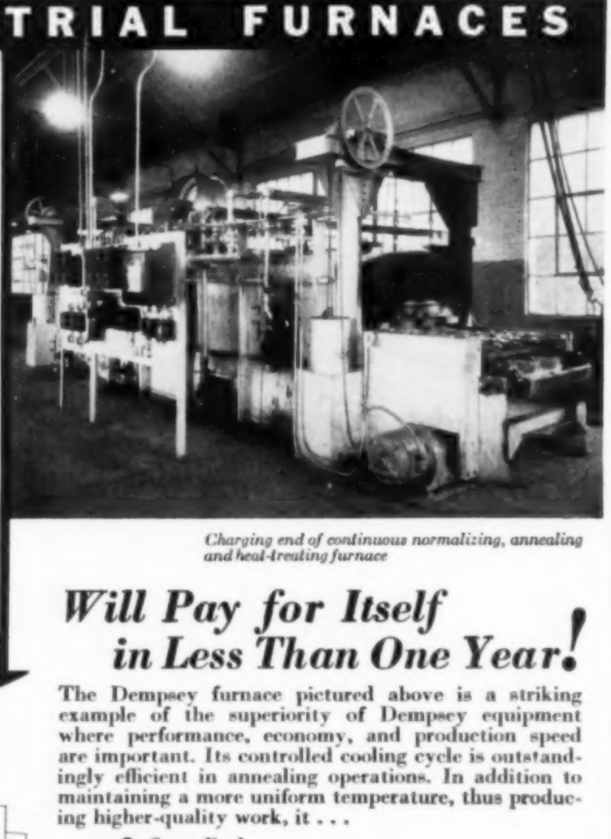

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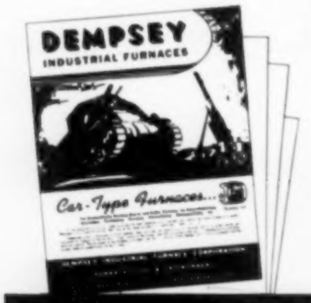

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"THE WILL TO MAKE GOOD STEELS"

SAVING CHROMIUM ALLOY

in heat resisting steels

By G. Riedrich

After citing the requirements of heat resisting steels, the Cr-Ni-Fe series of austenitic steels well known in America were cited for their excellent resistance to scaling and strength at high temperatures. Silicon up to 2½% and aluminum reinforce the scale resistance of chromium. As a means of obtaining a high proportion of austenite, nitrogen must now be considered along with nickel and manganese.

Manganese is regarded in Germany as a substitute for nickel; one well-regarded austenitic alloy contains 9% Cr, 1% Ni, 18% Mn, 3½% Si, and 0.10% C. It is resistant to scaling up to 1800° F. and has creep strength of 16,000 psi. at 1200° F. and 6000 psi. at 1400° F.

The ferritic Cr-Al steels, containing 20 to 30% Cr and 3 to 8% Al, are used almost exclusively for electrical heating elements and therefore are not treated in this article; however, a half-ferritic steel such as 6½% Cr, 1% Al, 1% Si, 0.10% C, and a ferritic steel with 10% Cr, 1½% Al, 1½% Si, 0.10% C have replaced the higher Cr-Fe alloys for scale resistance up to 1500 and 1650° F. respectively.

Embrittling changes in microstructure during a long stay at certain temperature ranges have been studied extensively. All categories of these alloys are subject to the disease. In the austenitic Cr-Ni (containing less than 30% Ni) and Cr-Mn-Si steels, there is the familiar carbide precipitation (or precipitation of FeCr sigma phase) at grain boundaries at 1100 to 1650° F. It is not possible to remove the tendency to embrittlement by alloy additions, since carbide-forming elements which reduce carbide precipitation also favor the precipitation of FeCr. Precipitation of FeCr sigma phase is not confined to the areas of massive ferrite, but also occurs in the austenite grain boundaries; however, the embrittling effect is mainly due to changes at and near the grain boundary.

In the ferritic steels embrittlement due to prolonged heating at temperatures over 1750° F. is brought about by carbide and FeCr precipitation and excessive grain growth. Additions of titanium or columbium will prevent the carbide precipitation, but will not eliminate the grain growth.

**Stahl und Eisen*, Vol. 61 (1941), p. 852 (translation in *The Engineer*, June 12, 1942, p. 499).

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